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## INTRODUCTION.

During the summer of 1913 the Secretary of Agriculture established a board reorganizing the system of publications of the Department of Agriculture. In accordance with the proceedings of the board and the suggestions from representatives of the Weather Bureau, the "Bulletin of the Mount Weather Observatory" ceased to be published with the completion of its volume 6. Any subsequent contributions from the members of the research staff that would have been proper for that Bulletin, will be incorporated in the Monthly Weather Review. The climatological service of the Weather Bureau will be maintained in all its essential features, but its publications, so far as they relate to purely local conditions, will be incorporated in the monthly reports for the respective States, Territories, and colonies.

Beginning with January, 1914, the material for the Monthly Weather Review will be prepared and classified in accordance with the following sections:

SECTION 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

SECTION 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

SECTION 3.—*Forecasts and general conditions of the atmosphere.*

SECTION 4.—*Rivers and floods.*

SECTION 5.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

SECTION 6.— *Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto.

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In general, appropriate officials will prepare the six sections above enumerated; but all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.

The voluminous tables of data and text relative to local climatological conditions that have during recent years been prepared by the 12 respective "district editors" will be omitted from the Monthly Weather Review, but will in future be collected and published by States at selected section centers.

The data needed in section 6 can only be collected and prepared several weeks after the close of the month whose name appears on the title page; hence the Review as a whole can only issue from the press about eight weeks of the end of that month.

Annual Summary to be the old Annual Report.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are especially due to the following directors and superintendents:

The Meteorological Service of the Dominion of Canada.

The Central Meteorological and Magnetic Observatory of Mexico.

The Director General of Mexican Telegraphs.

The Meteorological Service of Cuba.

The Meteorological Observatory of Belen College, Habana.

The Government Meteorological Office of Jamaica.

The Meteorological Service of the Azores.

The Meteorological Office, London.

The Danish Meteorological Institute.

The Physical Central Observatory, St. Petersburg.

The Philippine Weather Bureau.

The General Superintendent United States Life-Saving Service.

# SECTION I.—AEROLOGY.

## ATMOSPHERIC TRANSPARENCY FOR RADIATION.[1]

By F. E. FOWLE.

[Read Feb. 14, 1914, before the Philosophical Society of Washington, D. C.

A comparison of the transparency of the earth's atmosphere as determined by different observers at various altitudes with values derived by computation from the barometric height, the amount of aqueous vapor, and the transparency above Mount Wilson for dry air will be made in this communication.

### OBSERVED TRANSPARENCIES.

For observed transparencies of the air recent data from the following stations will be used: Mount Whitney, altitude 4,420 meters (**1**); Alta Vista, 3,260 meters (**2**); Pedrogil, 1,950 meters (**2**); Mount Wilson, 1,730 meters (**1**); Bassour, 1,160 meters (**1**); Orotava, 100 meters (**2**); Potsdam, 90 meters (**2**); Upsala, 50 meters (**3**); and Washington, 10 meters. The mean values for Washington were recomputed from the values given in volume 2 of the Annals of the Astrophysical Observatory of the Smithsonian Institution, omitting those dates when the transparency was apparently affected by volcanic dust. All the data for the other places were obtained during times probably free from such disturbance. The data will be found collected in Table 2.

### COMPUTED TRANSPARENCIES.

In the solar-constant work at Mount Wilson (**4**) coefficients of atmospheric transmission have been obtained at numerous wave lengths between $0.34\mu$ and $2.5\mu$.. It has been shown in an earlier communication (**5**) that these coefficients vary from day to day according to the amount of water vapor present in the atmosphere. The total quantity of atmospheric moisture present between the observing station and the limit of the atmosphere was measured by the spectroscopic method described in a yet earlier communication (**6**). The atmospheric moisture ranged from 0.27 to 1.77 centimeters of precipitable water, representing observations of 180 days. Coefficients of transmission for the dry air above Mount Wilson were derived for 30 different wave lengths from those observed for moist air by the following process: The logarithms of the observed transmission coefficients were plotted as ordinates against the corresponding quantities of precipitable atmospheric moisture as abscissæ, and the best representative curves (which appeared to be right lines) were produced by a short extrapolation to zero of moisture. From consideration of the slope of these right lines, factors expressing the effect of water vapor on the atmospheric transmission were determined for the 30 wave lengths mentioned. The process and results are given in more detail in the paper cited (**6**), from which is taken the following table:

[1] Published by permission of the Secretary of the Smithsonian Institution.

TABLE 1.—*Transmissibility of radiation through the air above Mount Wilson.*

| Wave lengths. | $0\mu.370$ | $0\mu.400$ | $0\mu.430$ | $0\mu.460$ | $0\mu.500$ | $0\mu.600$ | $0\mu.750$ | $1\mu.000$ | $1\mu.500$ |
|---|---|---|---|---|---|---|---|---|---|
| $a_{a\lambda}$ | 0.683 | 0.757 | 0.808 | 0.851 | [1]0.885 | [1]0.916 | 0.977 | 0.987 | 0.990 |
| $a_{a\lambda}$ (theoretical) | .680 | .755 | .808 | .850 | [1].890 | [1].946 | .977 | .987 | .986 |
| $a_{w\lambda}$ | .957 | .962 | .967 | .971 | .976 | .977 | .988 | .990 | .988 |

[1] Places of selective transmission.

The first line of the table contains $a_{a\lambda}$, the derived coefficient of transmission for dry air above Mount Wilson. The second line contains the corresponding coefficients as derived by Rayleigh's theory from the number of molecules in the air. The third line will be described below. In the formula $I_{m\lambda}=I_{o\lambda}(a_{a\lambda})^m$, if $I_{o\lambda}$ is the intensity of the incident beam of wave-length $\lambda$, then $I_{m\lambda}$ would be its intensity after passing through the mass of dry air $m$ where $m$ is unity for a celestial body observed in the zenith and is approximately (within 1%) equal to the secant of the zenith distance when the body is more than 20° above the horizon.

The theory and theoretical limitations of the method employed for determining the atmospheric transmission coefficients were given in volume 2 of the Annals of this Observatory, pages 13 to 17. The soundness of the method is confirmed by a comparison of the derived coefficients for dry air with those computed from Lord Rayleigh's theory of the atmospheric scattering of light: First, because, assuming that the depletion of energy is due wholly to scattering by the molecules of the components of dry air, the number of molecules per cubic centimeter of a gas (760 millimeters pressure, 0° C.), 26 billion-billion, determined through the transmission coefficients, corresponds very closely with what is perhaps the best figure, 27 billion-billion, as determined by other processes (**7**); second, because of the continued agreement of the computed and observed values over more than two octaves, except in the region of selective absorption near the D lines ($\lambda=0.53\mu$ to $\lambda=0.65\mu$), this agreement indicating a variation inversely as the fourth power of the wave length as would be expected from Rayleigh's theory of molecular scattering.

The third line of the table gives correction factors by which the dry-air transmission coefficients must be multiplied when the air vertically above the place contains an amount of water vapor which if condensed would form a layer 1 centimeter thick (1 centimeter precipitable water). The transmission coefficient for moist air vertically above Mount Wilson would then be $a_{a\lambda}(a_{w\lambda})^d$, where $d$ is the amount of precipitable water in centimeters in the atmosphere vertically above. The quantity $d$ is best determined spectroscopically (**8**) but in the absence of such determinations Hann's formula $d=ke$ may be used where $e$ is the vapor pressure in centimeters and $k$ a con-

stant for the place and equal to about 1.9 for Mount Wilson. The writer showed (**9**) that whereas redetermination by spectroscopic observations gave a mean value of $k=1.8$ above Mount Wilson, that agreed approximately with the value of Hann's formula, yet for individual days $k$ ranged from 0.33 to 5.20; accordingly little reliance should be placed upon this formula except when mean values for many days are under consideration.

While $a_{a\lambda}$, due to dry air, agrees very nearly with what would be expected from molecular scattering, $a_{w\lambda}$, due to water vapor, is much smaller than would be expected from a consideration of the number of molecules of water vapor present in the atmosphere and does not vary so closely with the inverse fourth power of the wave length. It behaves as if it expressed a scattering due to grosser particles which would deplete more uniformly than molecules throughout the spectrum. This possibly may indicate the association of dust with the water vapor, but perhaps more probably the formation of ions or nuclei under the influence of the ultra-violet radiation from the sun.

The more general formula for the transmission by moist air at any altitude, where the barometer is $\beta$ centimeters when the amount of precipitable water is $d$ centimeters and for any zenith distance of which $m$ is the secant, is—

$$(a_{a\lambda})^{m\beta/62}(a_{w\lambda})^{dm} \quad \ldots\ldots\ldots\ldots (A)$$

This formula has no factor allowing for the presence of dust and so is applicable only where the altitude renders the air comparatively free from dust. When the amount of aqueous vapor in the atmosphere is not known by spectroscopic or other exact methods, recourse must be had to Hann's expression, which, for any altitude, may be expressed as—

$$2.3\, e\, 10^{\frac{-h}{22000}}$$

where $e$ is the vapor pressure in centimeters at the place and $h$ the altitude in meters above sea level. As before stated, this, on the average, may give values approximately correct, although values for individual days may be several times too large or small. The use of formula A is as follows: Suppose 0.808 ($=a_{a\lambda}$) of the light at 0.431$\mu$ coming from a celestial body in the zenith, $m=1$, reaches an observer on Mount Wilson, where the barometer equals 62 centimeters and when the air is void of water vapor; and suppose, furthermore, that 0.967 ($=a_{w\lambda}$) of the remaining light would be transmitted were it to pass through 1 centimeter of water in the form of vapor. Then at any other place, for example, Alta Vista, where the barometer reads 50.9 centimeters and the precipitable water is 0.21 centimeter for $m=1$, the corresponding transmission is—

$$(0.808^{509/620}) \times (0.967^{0.21/1.00}) = 0.840 \times 0.993 = 0.834$$

TABLE 2.—*Observed and computed atmospheric transmission coefficients.*

| Wave length | $\mu$ 0.360 | $\mu$ 0.431 | $\mu$ 0.452 | $\mu$ 0.475 | $\mu$ 0.503 | $\mu$ 0.574 | $\mu$ 0.600 | $\mu$ 0.624 | $\mu$ 0.653 | $\mu$ 0.686 | $\mu$ 0.720 | $\mu$ 0.986 | $\mu$ 1.74 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $a_{a\lambda}$ | (.660) | .808 | .840 | .863 | .885 | .905 | .913 | .929 | .938 | .959 | .970 | .986 | .990 |
| $a_{w\lambda}$ | .950 | .967 | .967 | .973 | .977 | .974 | .977 | .978 | .985 | .987 | .988 | .990 | .990 |
| Mount Whitney, 4,420 meters: | | | | | | | | | | | | | |
| Dry air | .741 | .857 | .883 | .900 | .916 | .931 | .938 | .948 | .955 | .970 | .980 | .991 | .993 |
| Moist air | .738 | .855 | .881 | .898 | .914 | .929 | .936 | .946 | .954 | .970 | .980 | .991 | .993 |
| Observed | .741 | .845 | .872 | .904 | .920 | .932 | .940 | .948 | .955 | .962 | .969 | .975 | .956 |
| Departures [1] | −.004 | .012 | .010 | −.007 | −.007 | −.003 | −.004 | −.002 | −.001 | .008 | .011 | .016 | .037 |
| Alta Vista, 3,260 meters: | | | | | | | | | | | | | |
| Dry air | | .840 | .867 | .887 | .904 | .920 | .929 | .942 | .948 | .966 | .975 | | |
| Moist air | | .834 | .861 | .882 | .899 | .914 | .924 | .937 | .946 | .963 | .972 | | |
| Observed | | .822 | .850 | .872 | .888 | .904 | .910 | .922 | .941 | .958 | .965 | | |
| Departures [1] | | .013 | .012 | .011 | .012 | .011 | .015 | .016 | .005 | .005 | .007 | | |
| Pedrogil, 1,950 meters: | | | | | | | | | | | | | |
| Dry air | | .815 | .845 | .869 | .889 | .908 | .916 | .931 | .940 | .962 | .971 | | |
| Moist air | | .799 | .828 | .853 | .876 | .893 | .902 | .918 | .931 | .953 | .964 | | |
| Observed | | .800 | .823 | .846 | .869 | .885 | .909 | .910 | .922 | .932 | .939 | | |
| Departures [1] | | −.001 | .006 | .008 | .008 | .009 | −.008 | .009 | .010 | .022 | .026 | | |
| Bassour, 1,160 meters: | | | | | | | | | | | | | |
| Dry air | .643 | .796 | .830 | .855 | .877 | .910 | .908 | .925 | .933 | .957 | .968 | .984 | .989 |
| Moist air | .606 | .766 | .798 | .828 | .853 | .883 | .883 | .900 | .916 | .942 | .954 | .970 | .978 |
| Observed | .601 | .738 | .769 | .805 | .836 | .868 | .879 | .889 | .908 | .926 | .937 | .967 | .976 |
| Departures [1] | .008 | .036 | .036 | .028 | .020 | .017 | .004 | .001 | .009 | .017 | .018 | .003 | .002 |
| Orotava, 100 meters: | | | | | | | | | | | | | |
| Dry air | | .815 | .845 | .869 | .889 | .908 | .916 | .931 | .940 | .962 | .971 | | |
| Moist air | | .706 | .743 | .778 | .811 | .827 | .841 | .863 | .890 | .919 | .935 | | |
| Observed | | .666 | .699 | .727 | .754 | .776 | .786 | .801 | .818 | .837 | (.850) | | |
| Departures [1] | | .057 | .059 | .066 | .070 | .062 | .064 | .072 | .081 | .089 | .091 | | |
| Potsdam, 90 meters: | | | | | | | | | | | | | |
| Dry air | | .769 | .809 | .834 | .861 | .885 | .893 | .914 | .925 | .951 | .964 | | |
| Moist air | | .714 | .750 | .786 | .819 | .835 | .849 | .871 | .895 | .922 | .940 | | |
| Observed | | .702 | .726 | .752 | .777 | .806 | .828 | .840 | .851 | .861 | (.868) | | |
| Departures [1] | | .017 | .032 | .043 | .051 | .034 | .025 | .036 | .049 | .066 | .077 | | |
| Upsala, 50 meters: | | | | | | | | | | | | | |
| Dry air | | | .809 | .834 | .861 | .885 | .893 | .914 | .925 | .951 | .964 | .982 | .989 |
| Moist air | | | .774 | .806 | .836 | .857 | .866 | .889 | .908 | .936 | .950 | .968 | .975 |
| Observed | | | (.757) | (.772) | .791 | .824 | .834 | .848 | .869 | .889 | .900 | .939 | .942 |
| Departures [1] | | | .022 | .042 | .054 | .038 | .037 | .046 | .043 | .050 | .052 | .030 | .034 |
| Washington, 10 meters: | | | | | | | | | | | | | |
| Dry air | | .769 | .809 | .834 | .861 | .885 | .893 | .914 | .925 | .951 | .964 | .982 | .989 |
| Moist air | | .729 | .767 | .798 | .830 | .849 | .861 | .883 | .904 | .932 | .947 | .961 | .973 |
| Observed | | .629 | .664 | .706 | .735 | .769 | .784 | .802 | .828 | .853 | .865 | .918 | .930 |
| Departures [1] | | .137 | .134 | .115 | .114 | .094 | .089 | .092 | .084 | .085 | .087 | .050 | .045 |
| Washington, Feb. 15, 1907: | | | | | | | | | | | | | |
| Moist air | | .760 | .798 | .826 | .854 | .877 | .886 | .907 | .920 | .946 | .960 | .979 | .986 |
| Observed | | .735 | .769 | .834 | .837 | .850 | .870 | .875 | .900 | .910 | .910 | .955 | .948 |
| Departures [1] | | .033 | .036 | .010 | .020 | .031 | .018 | .035 | .021 | .038 | .052 | .025 | .039 |

| Place. | Mount Whitney. | Alta Vista. | Pedrogil. | Bassour. | Orotava. | Potsdam. | Upsala. | Washington. | Washington, Feb. 15, 1907. |
|---|---|---|---|---|---|---|---|---|---|
| Precipitated $H_2O$ | *Cm.* 0.08 | *Cm.* 0.21 | *Cm.* 0.64 | *Cm.* 1.20 | *Cm.* 2.57 | *Cm.* 2.21 | *Cm.* 1.26 | *Cm.* 1.57 | *Cm.* 0.33 |
| Barometer | 44.7 | 50.9 | 59.5 | 66.0 | 75.9 | 76.0 | 76.0 | 76.0 | 76.0 |
| Mean departure | .005 | .011 | .009 | .015 | .071 | .043 | .041 | .094 | .036 |

[1] Fractional departures of the observed from the computed values.

In Table 2 will be found, in 4-line groups, the comparisons for each station for a number of wave lengths. The first line of each group gives the transmissions computed from that for the dry air above Mount Wilson, taking into account only the difference of barometric pressure ($a_{a\lambda}^{\beta/620}$). They therefore represent the transmissions if no aqueous vapor were present. In the next line, these values have been multiplied by the correction factors for the mean amount of aqueous vapor present at each station ($a_{a\lambda}^{\beta/620}{}^{d}_{w\lambda}$). These mean amounts of aqueous vapor together with the barometer heights are given at the foot of the table. The third line of each group gives the mean observed values. The fourth line, the fractional departure of the observed from the computed values. The average of these departures for all wave lengths for the various places is given in the last line at the bottom of Table 2.

## CONCLUSIONS.

From Table 2 the following inferences may be made: The transparency of the air at any place depends on three factors: The transparency of dry air itself, which depends upon molecular scattering; the scatterings due to what may be termed wet haziness; and the scatterings due to dry haziness—the former associated with water vapor, the latter with dust. It is because of these associated disturbances, modifying the quality of the air with changing altitude at every wave length, that Bouguer's formula $a^{m\beta/760}$ for the transparency of the air can not be used in passing from one altitude to another. (In this formula $a$ is the transparency at the surface of the earth, $\beta$ the barometric pressure in millimeters, and $m$ the air mass.)

For those stations where dry haziness is present the formula developed in this communication can not be expected to hold. The fractional departures given in the fourth line of Table 2 may however be taken as the vertical absorption coefficients due to this dust. For Orotava these average 7 per cent; for Potsdam, Upsala, and for Washington, on February 15, 1907, about 4 per cent. The data indicate that, as would be expected, the dust absorption does not vary much with the wave length (**10**).

At an altitude of about 1,000 meters the disturbance due to dry haziness may disappear and then formula (A) can be used to compute the transparency on clear days with an accuracy of about 1 per cent.

At Bassour (1,160 meters) the correction to the dry air transparency because of the aqueous vapor present varies with increasing wave lengths from 6 to 1 per cent.

At the altitude of Mount Whitney (4,420 meters) water vapor has practically disappeared, and the scattering of radiation on clear days is due almost wholly to the molecules of the air alone.

Certain writers have criticized the method now almost universally used in the determination of the atmospheric transmission, implying that even at Mount Wilson and at Mount Whitney our estimations are 50 to 100 per cent in error. It would seem a strange freak of chance that the values of the solar constant of radiation, derived from measures of the intensity of the sun's radiation at altitudes of 4,420, 1,730, and 1,160 meters, corrected for the corresponding atmospheric losses, should agree within 1 or 2 per cent if the method of finding the coefficients of atmospheric transmission were likely to produce values so grossly in error. Added evidence of the correctness of the estimation of the atmospheric losses is furnished:

1. By the fact that the losses in dry air vary as the inverse fourth power of the wave length, over a range of wave lengths from 0.36$\mu$ to 1.74$\mu$ except where selective absorption exists;

2. By the agreement between computations of the number of molecules present in the atmosphere based on transmission coefficients and those by the most approved laboratory methods;

3. By the agreement (when dust becomes a negligible factor) between values obtained by observation at Mount Whitney, Alta Vista, Pedrogil, and Bassour and those computed for these stations from values observed at Mount Wilson.

Before concluding, the writer wishes to express his gratitude to Mr. C. G. Abbot for his criticisms and suggestions in the course of the preparation of this matter for publication.

## SUMMARY.

The transparency of the atmosphere on clear days is dependent on scattering due to three obstructions: The molecules of the air itself (dry air), hindrances associated with water vapor (wet haze), and ordinary dust (dry haze). It is due to the change in these last two factors with the altitude that the quality of the transparency of the air, even with homogeneous rays, changes and that Bouguer's formula for atmospheric transmission may not be used in passing from one altitude to another. These objections do not hold against its proper use with high and low sun observations at a single station.

Above an altitude of 1,000 meters on clear days the dry haze may become a negligible factor and the formula (A) developed in this communication can be used to compute the transparency to within 1 per cent.

Above Mount Whitney (4,420 meters) the wet haze on clear days may also become negligible and the obstruction offered to transmitted radiation is practically wholly due to the molecules of the air.

## REFERENCES AND NOTES.

(**1**) Abbot, Fowle & Aldrich, Annals of the Astrophysical Observatory, Smithsonian Institution, v. 3, 1913.

(**2**) Müller, G. Die Extinction des Lichtes in der Atmosphäre. (Astrophysikalische Observatorium zu Potsdam, Publikationen, No. 64, 1912.)

(**3**) Lindholm, Extinction des radiations solaires dans l'atmosphère terrestre. Nova acta, R. soc. scient. Upsaliensis, ser. 4, v. 3, No. 6, 1913.

(**4**) Annals, Astrophysical observatory, Smithsonian Institution, v. 3, p. 138.

(**5**) Astrophysical journal, 1913, v. 38, p. 392.

(**6**) Astrophysical journal, 1912, v. 35, p. 149; 1913, v. 37, p. 359.

(**7**) Millikan, Physical review, ser. 2, 1913, v. 2, p. 109.

(**8**) Astrophysical journal, 1912, v. 35, p. 149.

(**9**) Astrophysical journal, 1913, v. 37, p. 359.

(**10**) The general mean for Washington shows a decided decrease of the fractional departures with increasing wave-length, the values approaching about 4 per cent in the infra-red on the clearest day. This variation may be due to insufficient allowance for water vapor. No spectroscopic determinations of the water vapor were available, and except at Mount Whitney, Mount Wilson, and Bassour, Hann's formula was used to estimate the amount

## SECTION II.—GENERAL METEOROLOGY.

### PRESSURE IN ABSOLUTE UNITS.

By W. N. SHAW, Sc. D., F. R. S.

[Dated Dec. 16, 1913.]

From time to time, and especially within the last few years, the adoption of absolute units for representing atmospheric pressure has been urged on scientific grounds, and there is a general consensus of opinion that absolute units are the most suitable for dealing with meteorological theory, especially in relation to the upper air.

Through circumstances which are not altogether within my own control I have had to face the adoption of absolute units as a practical question and also as an educational question. In fact, I have had to ponder over replies to the following questions:

What units for pressure [and temperature] should be adopted in the publication of monthly values of pressure for a *réseau mondial?*

What units should be employed by lecturers and teachers who wish to interest students of mathematics and physics in the development of meteorological science?

What graduation should be employed for a barometer in order to commend most effectively to the wider public, the results of meteorological study?

I find the answer to all these questions in absolute units on the C. G. S. system, with only an outstanding uncertainty as to whether the millibar or the centibar is to be preferred.

Perhaps I had better explain that the *bar* represents the C. G. S. "atmosphere," that is, a pressure of 1,000,000 dynes per square centimeter, the dyne being the C. G. S. unit of force. The dyne is the force which produces an acceleration of 1 centimeter per second, per second, in a mass of 1 gram. The weight of $m$ grams when the gravitational acceleration is $g$ centimeters per second, per second, is $mg$ dynes. The bar is approximately equivalent to 750 millimeters, or 29.5 inches, of mercury at 0° C. and standard gravity. The centibar is one hundredth, the millibar one thousandth, of the bar.

It is quite possible that I may be to some extent affected by unconscious bias in favor of the ultimate application of theory to practice. If absolute units are the best for theory, they are the units of the future; for the practical applications of meteorology must ultimately be guided by theory just as those of astronomy are at the present day. For me this supplies the answer to my first question. The time is coming, if it has not already come, when students of meteorology will deal with the earth as a whole on the basis of observations and will recognize that anything short of that is inadequate for the solution of the more general problems of climate and weather.

To my second question, as to what are the best units for educational purposes, there is only one answer. So far as my own country is concerned, in all schools and colleges, wherever the elements of mathematics, physics, and chemistry are instilled into the rising generation, they are in association with the metric system as a part of scientific education. Two consequences result therefrom: In the first place, a complete divorce of all scientific experience from the meteorological practice of everyday life, a divorce which may perhaps be sufficiently illustrated if I say that in the laboratory a water bath of 98° is a very different thing from bath water of 98° in everyday life. The whole of the disastrous effect of this divorce is hardly to be appreciated by those who have nearly accomplished their life's journey with comparative success in spite of that disadvantage, but that is no reason for disregarding its importance to the young, and therefore let me call special attention to another aspect of it.

Between professors and students of the mathematical and physical schools of our universities there is a "freemasonry," of which the use of metric units is a sign and from which the students of meteorology are apt to find themselves excluded. To express my meaning in the fewest words, let me say that if in a country assembly for the advancement of science, an unknown stranger should get up and speak in metric units, the initiated physicist would at once say "he must be one of *us*," and the uninitiated meteorologist would say "he is one of *them;*" but if he should begin his discourse by speaking in inches and grains, the physicists would at once say "we need not listen—there can be no dynamics or physics in this," and in the most out-of-the-way meteorological assembly, if anyone should be heard speaking in metric units, he would not be set down as an eccentric or a crank, but as a person with exceptional scientific associations.

This being so, what should be the line of action of a meteorologist who lays claim to some portion of the scientific spirit? Surely this—not to remain in the isolation that excludes us from the sympathy of fellow-workers, but to turn the tables upon our friends and say to the grand masters of our cult, "We will accept a metric system, but we can not accept your millimeter, because when we make a change we must take care not to perpetuate the unscientific practice of representing the pressure of the atmosphere by a length. We know that the millimeter which you use is not really a length at all, and is really only a millimeter under conventional conditions of temperature and latitude which never occur together, but our students, who have yet to learn that important fact, will have clearer ideas from the start if they do not begin with that confusion. We are prepared to do what physicists have often aspired to do, but have not had the courage or coherence to carry out, namely, to use pressure units for pressure measurements and leave length units to measure lengths with. Nor can we accept your centigrade scale with the freezing point of water as its zero. We can not let our students adopt the conception of negative temperatures, which is a survival of the time anterior to the conservation of energy and which has sooner or later to be explained away with much labor and practical inconvenience."

Let us now deal with the third question: What kind of barometer should be put before the general public with due regard for the teachings of modern meteorology?

We know that it is still the practice to sell barometers with the customary legends—

| 28.0 | 28.5 | 29.0 | 29.5 | 30.0 | 30.5 | 31.0 inches. |
|---|---|---|---|---|---|---|
| Stormy. | Much rain. | Rain. | Change. | Fair. | Set fair. | Very dry. |

and that many newspapers reproduce day by day a barometer dial of this kind. On metric barometers we find the same legends, but "Change" is opposite to 760 millimeters instead of 29.5 inches and the steps are 10 millimeters instead of half inches. That is in itself sufficient condemnation of what on other grounds is quite intolerable, and in these days we want to suggest some alternative that will not spoil the instrument makers' trade nor yet convey to the countryman misleading ideas.

The first idea that an official meteorologist would suggest is that no countryman would have done his duty by the atmosphere unless he had compared his local reading with that of the corresponding issue of the daily bulletin. To do that he must reduce his readings to sea level, so, absolutely, the first requirement is a simple means for giving, with sufficient approximation, the sea-level pressure. The next idea to be inculcated is that the actual pressure of the atmosphere at the moment does not matter as a general rule, but only the changes which are taking place, and which can be watched locally with great advantage. What could be better for this purpose than to mark some point within the range of the barometer as 100 and note the differences from that point as percentages? Coming to details, it can only be regarded as providential that the point on the barometer against which the word "Change" is inscribed, being 29.5 inches, corresponds almost exactly with 100 centibars; consequently the temptation to use centibars and write 100 there is irresistible. Then obviously we must make the range of the dial or the tube big enough to show the changes which are to be expected in the district in which it is to be used, and the countryman will at once realize within what percentages of the middle value the pressure has varied in the past, and therefore may be expected to vary in the future. It is curious that 100 centibars, although not the mean value of the sea-level pressure, is in the middle of the usual range, and is, in fact, the middle line of the ordinary record sheet of a Richard barograph, which is marked 75 centimeters or 29.5 inches.

By way of suggesting that it is variations of the barometric pressure which count, and not the particular level, we can give the frequencies of occurrence of different barometric pressures, so that the observer can see for himself whether conditions are normal or exceptional, and so keep an eye on the working of his instrument as well as on the weather.

I have set out these suggestions in a *Land Barometer*, with a rotating circle for reduction to sea level. It is not necessary to enter into any further explanation; what is set out on the dial ought to be self-explanatory. But I ought to say a word about the frequencies. I can not now recall where I got the figures which are engraved on this first dial. I have made new figures for subsequent specimens, which give the average frequency of barometric minima below 100 centibars and maxima above 102 centibars, for Valencia, Aberdeen, and Kew combined. The figures are not applicable to any particular place without further inquiry, and their entry on the dial is a challenge to the observer to verify or improve them for his own locality.

With the *Sea Barometer* things are different. The observer has no daily weather chart at hand to show the distribution of pressure at sea level with which he can check the readings of his own barometer, and for any check he must rely upon the normals for his locality. Nor can frequencies of barometer values be easily given for a sailor whose course runs north or south. A barometer, on the pattern of the Land Barometer, for the transatlantic voyage might be made, but for the sailor who is not restricted to the transatlantic passage the normals for different latitudes along the thirtieth west meridian seem the most effective, and they are shown on the Sea Barometer dial.

These two barometer dials seem to suggest the centibar as the C. G. S. unit most likely to be useful in practice. So far no one has had any effective experience with instruments graduated to give pressure in absolute measure, and the millibar has given its name to the battlefield between the old and new, because it was adopted by Prof. Bjerknes as a substitute for the millimeter. Fortunately the difference between centibars and millibars is only the difference of a decimal point, and the practice as to observing and publishing may be allowed to shape itself as convenience in practice dictates.

While I am writing on the subject of absolute units I should like to add a word about the proposal of Prof. Bjerknes to record heights in "dynamic meters," which has given rise to fierce controversy. The quantity which it is really sought to express by the use of the term "dynamic meters" is the product $gh$, which is in fact the potential energy of unit mass at the height $h$. This quantity may quite appropriately be called the *geo-potential*, that is, the potential due to the earth's gravitational attraction at the height $h$. In the units which Prof. Bjerknes employs, the acceleration $g$ becomes numerically 0.981 for latitude 45°, and if $h$ is expressed in meters, $gh$ differs from $h$ by less than 2 per cent.

Thus the expression for the height in meters is numerically little different from the pressure of the *geo-potential* in what Prof. Bjerknes calls *dynamic meters*. The objection to the suggestion may be briefly expressed by saying that what is thought to be represented is not really height as generally understood, especially, for example, in a pilot balloon sounding, which is essentially a geometrical measurement, and the unit in which the geo-potential is expressed is not a *meter*, nor any fixed length; it has not the unitary "dimension" of a length.

The objection to changing the "dimension" of a unit by prefixing an adjective is perfectly sound, but it is really a curiosity of scientific literature to find the objection to the use of "dynamic meter" for the expression of geo-potential denounced as immoral in an article which stoutly upholds the use of the "time-honored millimeter" as a unit of pressure, without even an adjective as a warning to the unwary.

Mr. F. J. W. Whipple, of my Office, has proposed a solution of the difficulty which seems to me to meet the case in a satisfactory way. He points out that we have no special name for the unit of acceleration, and that in quoting the acceleration of gravity for a particular latitude we have to express it as, say, 981 centimeters per second, per second. He suggests the name *leo*, an abbreviation of the name of Galileo, of immortal memory in connection with gravitation, as a suitable name for the acceleration of a dekameter per second, and in this unit the acceleration of gravity in latitude 45° would be 0.981 *leo*. Then on the analogy of the *kilogram-meter* or the *foot-pound*, both time-honored as units of work or potential energy, a *leo-meter* would be the potential energy of unit mass raised through 1 meter against an acceleration of 1

"leo" or of unit mass raised through $1/g$ meters against the acceleration of gravity. Thus Prof. Bjerknes' "height" in *dynamic meters* would become the *geo-potential* in "*leo-meters*," and would differ numerically from the real height in meters only by about 2 per cent.

In this way all the objections on the score of morality or unsound terminology would be avoided, and yet the numerical value of the geo-potential in "leometers" would enable us to keep in mind a close approximation to the actual height in the consideration of the dynamic problems of the atmosphere.

It seems clear that the time has come when meteorologists may properly turn their attention to the reconsideration of their units and their nomenclature, and that the call comes with almost equal force from the theoretical, the educational, and the practical sides of their work.

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## THE WINDS IN THE FREE AIR.[1]

By CHARLES J. P. CAVE, Esq., M. A., J. P., M. R. I.

[Dated April 11, 1913.]

It was noticed in very early times that the wind in the upper air may be very different from what it is on the surface. Lucretius says: "See you not, too, that clouds from contrary winds pass in contrary directions; the upper in contrary way to the lower?" Bacon advocated the use of kites in studying the winds; but it is only in quite recent years that any systematic attempt has been made to investigate the free air above the surface of the earth. Kites have been flown to a height of 4 miles, but it is a matter of some delicacy to get even as high as 2 miles.

The temperature of the free air may be recorded by a meteorograph attached to a small rubber balloon, which continues to ascend until the pressure of the gas inside bursts the envelope, and the instrument descends again to the surface. The beautiful instrument constructed by Mr. W. H. Dines, F. R. S., the pioneer of upper-air research in England, is so light that the torn fabric of the balloon is sufficient to act as a parachute and check the speed of decent.

The general result of the observations has been to show that the temperature of the air decreases with height up to a certain point, above which the temperature distribution is nearly isothermal; however much higher the balloon may ascend, there is little further change of temperature. This upper layer, discovered by M. Teisserenc de Bort, whose recent death meteorologists of every country lament, is called the stratosphere; the lower part of the atmosphere is the part that is churned up by ascending and descending convection currents and is called the troposphere. The height at which the stratosphere is reached, as well as the temperature of the layer, varies from day to day and from place to place. In England it is met with at heights varying from about 8 to 14 kilometers, with temperatures varying from $-40°$ to $-80°$ C.

It is not, however, with temperatures that I am chiefly concerned to-night, but with the wind currents in the different layers of the atmosphere. If one of the balloons carrying instruments or if a smaller pilot balloon is observed with a theodolite, its position from minute to minute can be determined, and from its trajectory or its path as it ascends the winds that it encounters can be calculated.

The theodolite used is constructed specially for the purpose; a prism in the telescope reflects the light at right angles, so that the observer is always looking in a horizontal direction, even if the balloon is overhead. It is important that the observer should be in as comfortable a position as possible, for an ascent sometimes lasts over an hour and a half, during which time the observer can only take his eye from the telescope for a few seconds at a time; otherwise he may lose sight of the balloon and be unable to find it again.

The balloon having been started from one end of the base, observations are taken from both ends at exactly the same time, usually every minute. From the positions of the balloon at each successive minute, which are plotted on a diagram, the run of the balloon during the minute can be measured, and hence the wind velocity during that minute can be obtained. After the wind velocities have been measured off and the wind directions obtained from the directions of the lines on the diagram, another diagram is constructed showing the relation of the wind velocity and direction to the height.

It is not necessary to have two observers if the rate of ascent of the balloon is known; in such a case the complete path of the balloon can be calculated from the observations of one theodolite. It is not possible to know the rate of ascent with complete accuracy, as up and down currents in the air will affect the normal rate. In practice, especially in clear weather, the method is fairly satisfactory. The method of one theodolite requires less preparation, and the subsequent calculations of the path of the balloon are less laborious than in the case of observations taken with two theodolites from opposite ends of a base line.

The best time for observations is toward sunset, so that the balloon reaches its greatest height after the sun has set on the surface of the earth. At such times the balloon, still illuminated by the sun, shines like a planet; and on one occasion I should have found it impossible to tell which was the balloon and which was Venus except for the movement of the balloon. The distances at which balloons may be seen through the telescope of the theodolite are remarkable. A striking instance was when the flash of the sun on the small meteorograph was seen—not once, but repeatedly—when the balloon was about 9 miles above the sea and at a horizontal distance of about 30 miles.

In considering the structure of the atmosphere, as it has been revealed by the observations I have carried out, principally at Ditcham on the South Downs, we may divide the subject into two parts: (A) The wind structure in the lowest kilometer and (B) the general wind distribution up to the greatest heights reached by the balloons.

It is a matter of common observation that the wind increases above the surface, and in these days of aerial navigation it is important to know the law of this increase. It seems that at Ditcham the increase in velocity is at first linear or nearly so and that the line representing the linear increase passes through zero velocity at sea level; that is to say, if we plot the wind velocity at the surface and draw through it a line from zero velocity at sea level, the wind velocities at other heights, up to half a kilometer to 1 kilometer, will lie very nearly on this line. This approximately linear increase has been found to agree with observations at several land stations, but over the sea other conditions probably prevail.

But there are occasions when this state of things does not apply at all; this is often the case in light breezes and

[1] Reprinted by permission of the author from the Proceedings of the Royal Institution of Great Britain.

at times when the surface wind is very shallow, giving place to an entirely different wind régime in the first kilometer of height. At such times it often happens that the wind velocity is greatest a very little way above the surface. The fact that there are two separate conditions emphasizes the danger of taking means. By taking the mean value of a number of separate observations we might get as a result that the wind neither increased nor decreased in the first kilometer of height, which in reality is only true on very rare occasions. As has been truly said: "La méthode des moyennes c'est le seul moyen de ne jamais connaître le vrai!"

Another question of great importance to aviators is the effect of hills upon the winds blowing over them. The balloons used in my investigations ascend at the rate of 500 feet per minute and in a few minutes are carried beyond the reach of ground eddies. In some cases, however, I have found that a balloon rose with more than its normal velocity when passing over hills if a strong wind was blowing, and the effect is visible sometimes even when the balloon is more than a kilometer above the surface; on other occasions very little effect has been observed. More light is being thrown on this question by the observations of Mr. J. S. Dines on slowly ascending balloons.

The lower layers of the atmosphere up to 1 or 2 kilometers are the most important to *aviators*. To *meteorologists* the higher layers offer problems of greater interest. In considering the winds in the free air it is convenient to have some datum to which to refer them. The observed surface wind is not convenient for this purpose, being too much affected by local conditions near the ground. A better datum is what is known as the gradient wind. Under the influence of the barometric gradient the air is being pressed toward the areas of low pressure, but the wind is actually blowing more or less along the isobars at right angles to the force. In much the same way water in a basin, when allowed to escape through a hole in the center and when given a slight movement of rotation, moves round the basin at right angles to the forces which are pressing it toward the center. In the case of the atmosphere the turning movement is given by the rotation of the earth under the moving air. For any pressure condition to be maintained the air must be moving with a certain definite velocity, depending on the shape of the isobars and the steepness of the barometric gradient. This rate can be calculated for the conditions obtaining at the time, and the wind so calculated is called the *gradient wind*. It has been found that there is a fairly good agreement between the wind so calculated and the observed wind at a height of one-half kilometer or so, but owing to friction the surface wind is usually of a smaller velocity and directed more toward the low pressure.

In order to show in a clear manner the changes of wind at different levels, I have prepared some models which give a better mental picture of the conditions than a diagram. The atmosphere is supposed to be divided up into layers, each 1 kilometer thick, and the average wind in each layer is represented by a colored card; the length of the card represents the velocity of the wind, 1 centimeter representing 1 meter per second, 1 meter per second being about 2¼ miles per hour; the direction of the card shows the direction of the wind, the arrow flying with the wind. The red cards represent winds that may be supposed to come from an equatorial direction—that is, winds from east-southeast through south to west-northwest—the blue card winds that may be supposed to come from a polar direction.

For convenience I have divided the wind structures into five types; they are perhaps rather artificial, as I shall show later, but it is convenient to make some sort of classification, even when further knowledge must change it. In the first three types of wind structure, the wind increases above the surface and equals the gradient velocity at a height of one-half kilometer or so; above this in the first class the wind remains more or less equal to the gradient velocity up to a height of 7 or 8 kilometers; in the second class the wind in the upper air greatly exceeds the gradient wind, and in the third class it falls off again to a lesser value; but in all three classes the direction remains much the same as that of the gradient wind.

The first type may be called the solid current; it does not seem to be associated with any particular type of isobars, but in a preponderance of cases the wind is easterly and the remaining cases are nearly all westerly; it is rare to find the solid current with winds from the north or from the south.

In rare cases there is hardly any wind up to the greatest heights reached, and the little wind there is often blows

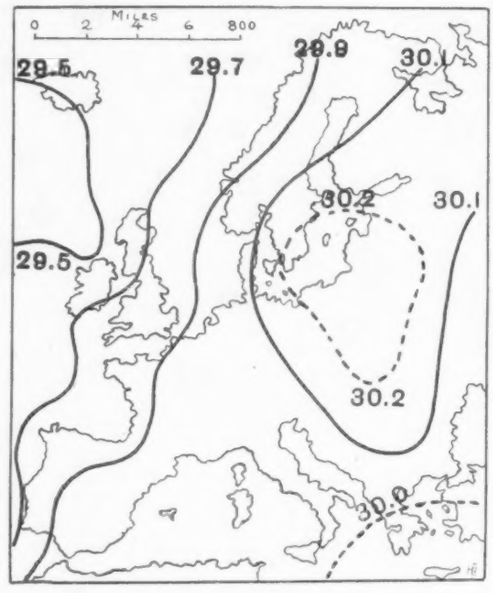


FIG. 1.—Isobars at sea level 1907, May 11, 6 p. m.

from varying directions in different layers. This type, which may be looked on as a subclass of the first type, sometimes occurs in still anticyclonic conditions in summer.

In the second class the gradient wind, after being reached at a height of about one-half kilometer, is greatly exceeded in the upper air; in some cases the wind at 2 or 3 kilometers is double the gradient value, or even more. This type is likely to occur when there is a low pressure to the north of the station and when there is a strong temperature gradient, such that the low temperatures correspond to the low pressures and vice versa. Such conditions should theoretically cause an increase in wind velocity in the upper air, but it is not possible to calculate what the effect should be without knowing the temperatures not only on the surface but in the upper air over the region in question. One may, however, calculate what effect surface temperatures would have on the isobars—at, say, 3 kilometers—assuming that the vertical temperature gradient is the same at every point. A map

constructed to show the isobars which have been thus calculated must be looked on as a rough approximation only to the real conditions. A map of isobars at 3 kilometers for May 11, 1907, based on figure 1, shows how much steeper was the gradient on this day in the upper air than it was on the surface, a fact which quite accounts for the rapid increase in wind velocity from 2 meters per second at the surface to 19 meters per second at 3 kilometers.

Winds belonging to this class may come from any point of the compass.

The third class comprises those cases in which the wind, after reaching the gradient velocity in the first one-half kilometer or so, falls off more or less rapidly in the upper air. This class is almost entirely associated with easterly winds on the surface, when there is high pressure to the north and low pressure to the south. An east wind is usually, though not always, a shallow one; a southwest gale increases in the upper air, but when an easterly gale is blowing, causing such high seas and such dangers to shipping, it is curious to reflect that such a short distance up we should meet with light breezes or even a complete calm.

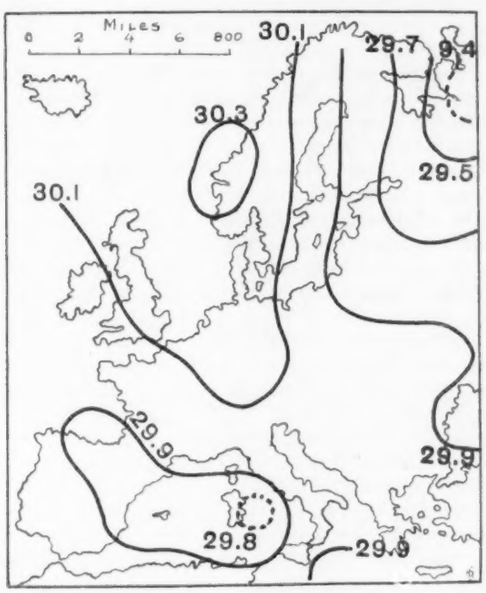


FIG. 2.—Isobars at sea level 1908, November 6, 6 p. m.

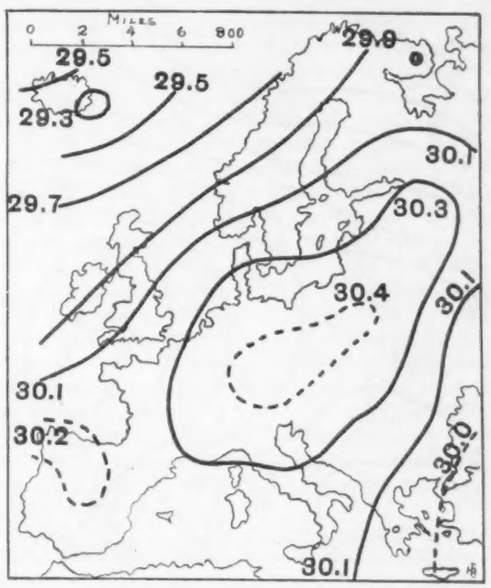


FIG. 3.—Isobars at sea level 1908, September 30, 6 p. m.

We now come to the class of reversals when the wind in the upper air is very different in direction from that near the surface, and when it often bears no relation to the surface pressure distribution. In a typical case, after an initial increase for a short distance above the surface, we find the wind gradually decreasing as we ascend, till a layer is met with, in which there is a complete calm; above this we find an entirely different wind, which usually increases as we go higher, as in the case of winds in the second class. It looks at first sight as though there were a discontinuity in the atmosphere, but I hope to show later that this is more apparent than real. A typical example of a reversal occurred on November 6, 1908 (see fig. 2), when the surface wind was easterly with a velocity of 17 meters a second, just below 1 kilometer; above this it fell off to a complete calm at 3 kilometers; at 4 kilometers there was a light northwest wind, which increased to a wind of 15 meters per second at 10 kilometers. The weather map for this day is remarkable; over this country there is no sign on the surface of the westerly wind above, but it appears that in Germany, where the pressure was highest, the westerly wind must have been descending and must have divided into two currents, one flowing on as a westerly wind over eastern Europe, the other flowing back as the easterly wind recorded in this country.

There are other cases of reversal which are not so simple as the one described above. In many cases this type is associated with small depressions or with small areas of high pressure which seem to be relatively shallow. The surface winds are related to these shallow systems, while the upper winds are controlled by larger areas of high and low pressure, shown on the weather maps at places lying farther from the point of observation.

On September 30, 1908 (see fig. 3), for instance, a southerly surface wind, after remarkable backing, gave place to a calm at 3 kilometers; above the calm another southerly wind is met with; in this case the surface wind is probably related to the high-pressure system over Germany; the upper wind to the depression approaching from the Atlantic. There was another somewhat similar case on November 16, 1908 (see fig. 4), though with winds from a different direction. The northerly surface wind backed, and a calm was met with; above this, very unexpectedly, came a thin stream of southerly wind, above which again was a north wind, increasing in velocity with height. In this case the lowest wind was part of the circulation of an anticyclone which was approaching these islands from the Atlantic. The intermediate southerly wind was perhaps the last remaining effect of the anticyclone over the Continent, while the upper wind was the outflow from above a depression near Iceland, a wind which belongs to another class to be noticed later.

In cases of reversal we find that the warm wind flows over the top of the one that comes from a colder region: there must somewhere be a line where the warm current is rising, where it must be cooled dynamically, and where its moisture may condense into cloud or rain. It is interesting to note that in most cases rain occurs somewhere in the region of the reversal, and in summer thunderstorms are frequent. Thunderclouds may often be seen to be in

a wind coming from a contrary direction to the wind on the surface, and it seems possible that for anything like a sustained thunderstorm something in the nature of a reversal must exist. It is difficult to see how a difference of potential sufficient to produce lightning can be kept up unless winds from different directions are bringing masses of air at different potentials near to one another.

It has been noticed in Hampshire that when the sound of gunfiring in the Channel is distinct it is, in summer, a sign of thunder. An explanation may be hazarded: If there is a reversal so that the upper wind is coming from the south, the sound waves traveling from this point with a slight upward tendency will be refracted on entering the upper current, and thus, instead of being dissipated in the upper air, may again reach the surface at a considerable distance from their point of origin. Such conditions of wind are those productive of thunderstorms. This may also possibly account for the superstition that gunfiring produces rain. The sound of guns is only carried to great distances under the conditions I have mentioned, which are precisely the conditions favorable for heavy rains.

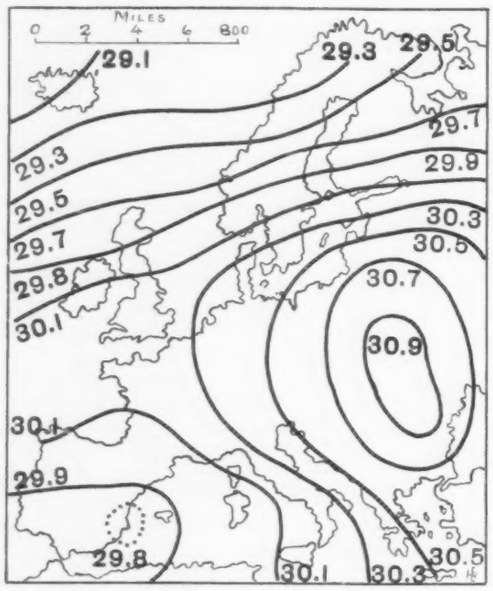


FIG. 4.—Isobars at sea level 1908, November 16, 6 p. m.

A northeast wind with rain lasting many hours is a common and a very unpleasant type of weather; it is not obvious where the moisture comes from with such a wind, for the air from the dry regions of the Continent could hardly become saturated in its short passage over the North Sea. I believe the moisture comes from the Atlantic in a southwesterly wind in the upper air. Balloons can not be followed for any length of time in such weather but I have sometimes observed that the northeasterly wind slackens considerably below the cloud level, and sometimes, when breaks in the clouds have enabled balloons to be followed a little farther, there have been unmistakable signs of reversal. A careful watch for upper clouds, seen through rifts in the lower cloud sheet, will often indicate an upper southerly wind. So sure do I feel of these facts that though living only 12 miles from the Channel I never hesitate to send up an instrument-carrying balloon in rainy weather with a northeasterly wind, feeling sure that, though the balloons may go toward the sea at first, they will ultimately return and fall on dry land. My confidence is usually rewarded, the balloons coming to earth in the midlands, or eastern counties.

The last type of wind structure to be considered is the outflow that seems to take place from the upper layers over a low-pressure system, causing west to north winds in the upper air on the east and south sides of the depression. Depressions out in the Atlantic, which cause southwest winds on the surface, give rise to west or northwest winds in the upper air over England; even cyclones as far off as Iceland produce such winds, and as they pass along the Arctic Circle, between Iceland and Norway, they show their presence by an upper northerly wind over this country. As the upper wind is often quite different from that on the surface, reversals are frequent in this class, and are associated as usual with rains and with thunderstorms in the summer. It may be that much of the rain that falls in the cyclonic depression is due to the rising of this outward flowing current over the very different surface current on the east and northeast sides of the depression.

In connection with the subject of reversals, I may mention the wave and ripple clouds that form such beautiful skyscapes. It used to be supposed that these were formed by winds from different directions flowing over one another and setting up waves; but the observations of pilot balloons have shown that between two currents from different directions there is either a layer of calm, or else the wind changes round gradually; two very different currents are not found in close juxtaposition: there is no abrupt transition between them.

To show relation of the different types of wind structure to the surface pressures, a model has been prepared; on the map are shown a depression and an area of high pressure, with arrows to show the wind directions; above the map is a sheet of glass to represent the first 5 kilometers of the atmosphere; on this are marked the winds one would expect to meet with at this level under the conditions of pressure supposed; above this sheet of glass is another representing the thickness of the atmosphere from the 5-kilometer level to the stratosphere. The model is on the scale of one-millionth, the vertical scale through the glass being approximately the same as the horizontal scale.

The churning up of the air resulting from the heating of the surface layers by contact with the earth heated daily by the sun, does not presumably reach into the stratosphere; there being no vertical movements, we should expect to find only such horizontal movements as are consistent with a suitable distribution of density. In the simplest cases the wind increases in velocity till a maximum is reached just below the stratosphere; above this the wind begins to diminish, and sometimes falls off in a very marked manner. There are occasions when all real wind seems to have ceased, and the balloon as it ascends through this curious region moves first in one direction and then in another, so that the relation of wind direction to height can only be represented on a diagram by a disconnected series of points.

What takes place still higher? Does this region of calm extend to the very confines of the atmosphere? We have practically no evidence to go on. On February 22, 1909 (see fig. 5), a meteor left a magnificent streak which was visible for two hours and a half; this trail, which was some 40 miles above the surface of the earth, moved in a manner suggesting very high wind velocities, with sudden variations in the different layers through which it passed. But it is possible that the streak of a meteor may partake of the nature of an aurora, whose luminous

patches sometimes move in a remarkable way, and probably under forces other than those of the winds.

Having for purposes of classification divided the wind structure of the atmosphere into different classes, I must now attempt to put them together, and to show that some of the types that seem very different are in reality closely connected.

Following on inquiries made by Mr. W. H. Dines on the correlation between the surface pressure and various meteorological elements at a height of 9 kilometers, it was suggested by Dr. W. N. Shaw, F. R. S., that the changes of pressure to which our changes of weather are due, have their origin, not near the surface of the earth as hitherto supposed by many meteorologists, but just below the level of the stratosphere at a height of 9 kilometers or so above the surface. This view is in accordance with the observed facts of the wind distribution in the different layers of the atmosphere.

Supposing that on a certain day there is a pressure distribution just below the stratosphere, which at that level produces a westerly wind of a certain strength;

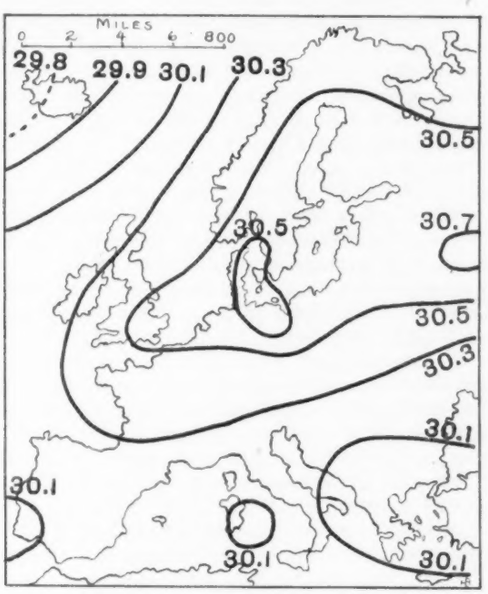


FIG. 5.—Isobars at sea level 1909, February 22, 6 p. m.

this pressure distribution will be transmitted through all the lower layers of the atmosphere, and unless modified by other conditions will produce a west wind at the surface; the velocity of this wind will, however, be only about one-third of that at the 9-kilometer level owing to the greater density of the air near the surface. If, however, the air to the north at every height were at a lower temperature than the air at a corresponding height over the place of observation, there would be at all levels a tendency for easterly winds. This will have the effect of reducing the westerly wind as we descend through the atmosphere, and when the surface is reached the west wind will have a much lower value than it would have had were it only for the increased density of the air. If the wind at the 9-kilometer level is not very strong, or if the tendency to produce an easterly wind is strong, as would be the case if the air to the north were very cold we may get a calm at the surface, or the calm may even be reached at some distance above the surface, in which case the tendency for easterly winds may actually produce such a wind which will increase in velocity as we descend toward the surface under the layer of calm and be strongest a little above the surface of the earth at a point where surface friction begins to cause a diminution of velocity.

If again at the 9-kilometer level there is a pressure distribution producing an easterly wind cold air to the north will produce a tendency for an increase of easterly wind as we descend through the atmosphere; but the greater density of the air at the lower levels will produce a decrease of wind velocity from whatever direction the wind may be coming; the two tendencies may neutralize one another in which case we get a solid current of east wind between the stratosphere and the ground level.

If there is no wind at the 9-kilometer level cold air to the north will produce easterly winds in the lower levels in which case we should find easterly winds increasing in velocity as the surface is approached.

These considerations give some idea of the mechanism by which the different types of vertical wind structure may be produced. The wind increasing with height, the solid current, the wind decreasing with height, are seen to fall into their places. The reversal, with an east wind near the surface and a west wind higher up, is only an extreme case of the slackening of the westerly wind near the surface; and the point of reversal, far from marking a point of discontinuity in the atmosphere, is seen to be merely the result of forces extending right through the lower part of the atmosphere, between the stratosphere and the earth.

If the winds are resolved into components at right angles to each other, that is north-south, and west-east components, it is found that in most cases the west-east component decreases below the stratosphere and is a minimum near the surface, an east wind in this case being considered as a negative west wind. This is what should be the case if the ideas I have been considering are correct, for the air to the north is generally colder than the air over this country. In the case of the north-south component we find no such general rule, but this also is as it should be, for the air to the east and west may be either of the same temperature, or warmer, or colder than the air over the station, in other words, there is a normal north to south temperature gradient but not a normal west to east gradient, in our islands.

The supposed cases mentioned are of course simple types, and it can be readily understood how varying conditions of pressure and temperature may in similar ways produce varieties of vertical wind distribution. In considering the pressure distribution just below the stratosphere as the regulator of the winds and the weather in the lower part of the atmosphere, I fear I have nothing to add concerning the laws governing these pressure distributions; the idea is a new one and has yet to be worked out in its details, and to stand the test of criticism and fuller investigation.

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## METEOROLOGY AS AN EXACT SCIENCE.[1]

By Prof. Dr. VILHELM BJERKNES.

[Delivered at the University of Leipzig, Jan. 8, 1913.]

It is a time honored custom that the newly appointed professor in his inaugural address should devote a few words to his predecessors by way of commemoration. I can not follow this example; therefore, ought I to be so much the more grateful for the honor of having been

[1] Die Meteorologie als exakte Wissenschaft. Antrittsvorlesung gehalten am 8. Januar 1913 in der Aula der Universität Leipzig. Braunschweig. 1913. 16 p. 8°.

chosen as the first occupant in this university, of the new chair of geophysics.

Just as the earth is a part of the entire cosmos, so geophysics can be conceived as a part of cosmical physics. It is divided into three branches: Physics of the atmosphere, Physics of the hydrosphere and Physics of the rigid earth; and has thus an extraordinarily extensive scope. It will not be easy to succeed in treating satisfactorily at one time all the branches, and I believe it to be consistent with the conditions of my call to this chair, if I direct my personal field of action as investigator and teacher to the first two branches particularly. These two are closely related to each other, and I can elucidate the points of view which I desire to place in the foreground in this lecture on the first branch, that is, the Physics of the atmosphere.

The physics of the atmosphere treats of the same subjects as meteorology. For this very reason, however, these two sciences must not be confounded with each other. The distinction is marked for the reason that physics ranks among the so called exact sciences, while one may be tempted to cite meteorology as an example of a radically inexact science. Meteorology becomes exact to the extent that it develops into a physics of the atmosphere. I shall consider this development in the present lecture.

Man has always entertained a keen interest in the weather and in atmospheric phenomena. Even in the infancy of scientific research, he made this a hobby of speculation. We see this equally in the serious writings of Aristotle, and in the romping comedies of Aristophanes. The beginnings of a meteorology already existed among the ancients. They were able very exactly to define not only their own weather phenomena, but also the peculiarities of the grand, impressive, strictly scientific phenomena of the Tropics such as the Indian monsoon. They also possessed a not inconsiderable knowledge of physics. Archimedes had founded a rigorous system of hydrostatics; and the expansion of air by the application of heat was also known. Upon the latter were based various of the famous juggleries of Hero. Not one of the ancients, however, dared to combine this varied knowledge in order to explain, for example, the cause of the monsoon or any wind in fact. Consequently we can not well discuss the physics of the atmosphere, or more generally speaking, geophysics among the ancients.

In the age of the great geographical discoveries, meteorological information also expanded particularly with respect to the weather conditions of the Tropics. Still more steadily than the monsoon, blow the trade winds which Columbus discovered on his first voyage. Upon further exploration, the trade winds were found in the southern hemisphere, and the knowledge of the monsoon was reinforced.

Contemporaneously physics began to develop into a systematic science. In the later Renaissance dynamics was founded, the principles of hydrostatics rediscovered, and the effect of applying heat to bodies more minutely inquired into. This prepared the way for some investigating spirit to perceive, sooner or later, the relationship between the winds of the Tropics and an unstable equilibrium produced by heat. The first one to express this happy idea was Newton's friend and pupil Halley, when he returned in 1686 from a two-year voyage through the Tropics. His conclusion was that heated air is lighter than cold air and must therefore rise, being displaced by inflowing currents from below and round about. Thus over the thermal equator an ascending current forms, fed by two currents of air blowing longitudinally over the earth toward the equator, i. e., the trade winds of the Northern and Southern Hemispheres. The Indian monsoon originates in like manner. Here the warmest place, over which the ascending air current rises, is the Asiatic Continent or the Indian Ocean, according to the season. Hence the seasonal change of the monsoon.

Halley's explanation of the origin of the trade winds and the monsoon has held true for all time. On the other hand, he incorrectly explains the phenomenon that the trade wind has a component in the direction of the equator instead of flowing perpendicularly to it. This point in his theory was corrected and completed about 50 years later by Hadley, another English astronomer. By means of a well-known elementary consideration, which is frequently presented even in geographical textbooks, he demonstrates that the wind is not actually deflected but only appears to be so to the observer who is traveling with the rotating earth.

Through the efforts of these two English astronomers, so similar in name, the relationship between the two sciences of meteorology and physics first came to be recognized, and the first step was taken toward the development of a physics of the atmosphere. We may here advantageously compare the great revolution in astronomy which just preceded this advance. Newton had applied dynamics, which had sprung from other than astronomical sources, to the phenomena of the heavens, and had thereby been able to explain the stellar motions. Halley and Hadley had applied a knowledge of the theory of heat, hydrostatics, and dynamics, derived from other than meteorological sources, to the phenomena of the atmosphere and had thereby explained the great movements of the atmosphere. The results of both these advances were similar. The subsequent discoveries in the motions of the solar system were without exception based upon Newton's laws; and those concerning the motions of the atmosphere were all traceable to the fundamental principles established by Halley and by Hadley. All the latter were directly or indirectly due to heating, and all, excepting the cases of purely local winds, show the influence of Hadley's theory of deflection. The essential difference, however, between meteorology and astronomy was that atmospheric motions could only be studied qualitatively, whereas stellar motions might also be studied quantitatively and indeed so accurately that, from the known position of a star at one time, its position could be successfully predicted for a remote date. Consequently by that one stroke astronomy became an exact science, while meteorology had taken only its first step in that direction.

It is self-evident that there should be this difference. Astronomical observations yielded all the data necessary for predicting the positions of the stars. On the other hand, at that time meteorological observations were quite unable to furnish suitable fundamental data for predicting atmospheric conditions. In mathematical calculations, the heavenly bodies may be regarded as individual points which move in the simplest manner under mutual influences. Newton's Mechanics was designed for precisely such conditions, and not for the handling of the motions of a continuous medium, such as the air. The quantitative laws governing the interchange of mechanical and thermal processes had not yet been discovered. The transformation of meteorology into an exact science necessarily called for the extensive further development

of physics, on the one hand, and of observational meteorology, on the other.

It would take too much time to delineate in detail the parallel development of the two sciences. I must limit myself to a few essential points.

Galileo and his pupils constructed the first thermometer; Torricelli made the first barometer. These instruments lent to observational meteorology a precision it had previously lacked. As time went on it became evident that the study of simultaneous observations would be extremely fruitful, and several students laboriously collected these and began to present the results by means of synoptic charts. The work of H. W. Brandes published at Leipzig in 1820 and 1826, the latter date being that of his University Dissertation, are among the most important of those to be mentioned in this connection, though they did not immediately meet with the appreciation that they merited. At about this same time Redfield in America began to draw his synoptic charts.

At last the storm of November 14, 1854, over the Black Sea caused so much damage to the fleets of the combined Western Powers that it gave the needed impetus toward a speedier development of the science. The eminent astronomer Leverrier received an official order to study conditions of that storm with a view to the possibility of foreseeing such occurrences and the establishing of a storm-warning service. Upon this foundation rose the present organized international telegraphic weather service.

Great as was this advance, still the resulting Weather Service could not meet the very great expectations that it originally excited. Quite properly, one sought the true ground for such disappointments in the observational scheme. All the observations available came from the lower limit of the atmosphere. Almost no information was available concerning the conditions in the free air. It is true that after the balloon was invented, occasional ascents had been undertaken with the object of securing meteorological observations. The ascensions by Glaisher in England are especially noteworthy, although they were attempted with an instrumental equipment that was still inadequate to the task. A more accurate method for securing meteorological observations under these new conditions was first developed by Assmann in the course of that splendid series of Berlin ascensions executed during the last decennium of the last century. Shortly thereafter methods were devised for securing observations in the free air without necessitating the ascent of the investigator himself.

We owe the first step[1] in the development of this "aerological" method of observing to an American, the late A. Lawrence Rotch. By means of kites he sent up self-recording instruments from his observatory at Blue Hill, near Boston. Later, L. Teisserenc de Bort, in France, sent up similar instruments attached to small unmanned balloons, which descended to earth somewhere after completing their trip; most of these were subsequently picked up and returned to him. Assmann replaced Teisserenc de Bort's paper balloons with closed rubber balloons which burst when high up in the air, after which the instruments descend with a parachute. In this way the journey is performed quicker and there are greater chances of recovering the instruments. In addition to kites and registering balloons, small captive balloons are also employed. Further, small free balloons without any attached instruments, so-called pilot balloons, are employed to observe only the atmospheric motions; these are observed by means of a theodolite.

To-day a large number of aerological observatories are at work with these auxiliaries, the largest one being the Royal Prussian Aeronautical Observatory, founded by Assmann, at Lindenberg. Moreover, and mainly through Hergesell's initiative, there exists an organized international cooperation among the aerological observatories; moreover, a series of occasionally contributing institutes has also been developed. On certain prearranged days an extensive region of the free atmosphere is investigated. This region extends from the west coast of Europe across central Europe far into Russia; each year sees it expanded and more thickly studded with aerological stations. The atmosphere over this territory is sounded to heights of 15 or even 20 kilometers or more. Since at these altitudes the atmospheric pressure is reduced to but one-tenth to one-twentieth of that at sea level, it is obvious that as much as nine-tenths or more of the mass of the superincumbent air of this extensive territory is now being explored. This investigation includes directly, or indirectly, all the meteorological elements that define the condition of the atmosphere, seven quantities in all: the three velocity components, also the pressure, temperature, density, and humidity of the air. On the days of international observation the values of all these elements are determined, first at the various observing stations and then by suitable methods of interpolation they are deduced for all points of the territory. Thus observational meteorology has practically completed and perfected her task, no matter what future advances may yet be made in instruments and in organization.

Parallel with this development of meteorology has been the extensive advance in experimental and theoretical physics since the Renaissance. I can mention here only the principal milestones that are the most important for our subject.

Analytical mechanics has developed on the foundations laid by Galileo and Newton. About the middle of the eighteenth century Clairaut established the equations of hydrostatics, and Euler did the same for those of hydrodynamics. About 1820 Navier supplemented these equations by adding those terms that represent the effect of internal friction. In 1835, exactly 100 years after the true pioneer Hadley, Coriolus presented his well-known theorem in dynamics, now generally used in dynamic problems to express the effect of the earth's motion.

After the invention of the barometer and the thermometer it was possible, by their aid, to investigate the laws of gases, and we gradually came to the complete Boyle-Gay-Lussac law. We learned to discriminate between the idea of temperature and the idea of quantity of heat, and established the laws of melting and freezing, evaporation and condensation. In continuation of this development and guided by the new fundamental ideas of Sadi Carnot and Robert Mayer, the early years of the nineteenth century saw the growth of the modern theory of thermodynamics for whose development and completion we are indebted to von Helmholtz, Kelvin, and Clausius.

In like manner physics has rendered the service that was demanded of it. I have already mentioned the seven variables which we call "meteorological elements." As a result of the progress that I have outlined, physics is now able to formulate the seven corresponding equations, viz, the three hydrodynamic equations of motion, the equation that expresses the principle of the conservation of mass (the so-called "equation of continuity"), the equa-

[1] See, however, this issue of this Review, p. 39.—EDITOR.

tion of condition for gases, and the two equations that result from the two fundamental theorems of thermodynamics. By means of these equations together with the necessary boundary conditions and the data relative to external influences, the problems of dynamic meteorology become definite formulated problems from a mathematical point of view. Theoretically speaking, they can now be attacked both qualitatively and quantitatively with some hopes of success.

The theoretical treatment of meteorological problems has kept pace with the development of observational meteorology and theoretical physics. At first idealized phenomena were discussed. By making appropriate assumptions, one or more variables may be eliminated, and thus one may devise problems of a purely dynamic or of a purely thermodynamic character. By still further simplifying assumptions we obtain corresponding simple integrable systems of equations whose solutions are essential to the comprehension of various meteorological phenomena. Ferrel, Guldberg and Mohn, Helmholtz, Hertz, Von Bezold, and others have given us valuable works of this character. To a certain extent Hann's theoretical works are also related to this class, since they aim at more precise general elementary explanations of meteorological phenomena.

All these works antedate the founding of modern aerology. But now that complete observations from an extensive portion of the free air are being published in a regular series, a mighty problem looms before us and we can no longer disregard it. We must apply the equations of theoretical physics not to ideal cases only, but to the actual existing atmospheric conditions as they are revealed by modern observations. These equations contain the laws according to which subsequent atmospheric conditions develop from those that precede them. It is for us to discover a method of practically utilizing the knowledge contained in the equations. From the conditions revealed by the observations we must learn to compute those that will follow. The problem of accurate pre-calculation that was solved for astronomy centuries ago must now be attacked in all earnest for meteorology.

The problem is of huge dimensions. Its solution can only be the result of long development. An individual investigator will not advance very far, even with his greatest exertions. However, I am convinced that it is not too soon to consider this problem as the objective of our researches. One does not always aim only at what he expects soon to attain. The effort to steer straight toward a distant, possibly unattainable point, serves, nevertheless, to fix one's course. So, in the present case, the far-distant goal will give an invaluable plan of work and research.

Here I may be permitted to draw an illustration from my personal experience. For many years I had already occupied myself with the application of the laws of hydrodynamics to the motions of the atmosphere, and had come to many interesting results. But the question kept recurring to me: What is it that I really seek? Whither am I steering? I could not free myself from the thought that "There is after all but one problem worth attacking, viz, the precalculation of future conditions."

As I had been able to find enthusiastic young colaborers who had the courage to follow me, I determined to always steer directly toward this distant goal.

We have never regretted it. To be sure the work we have already accomplished seems but to emphasize how far removed our goal really is. Yet our work has always been fruitful. Precisely because we have always kept the end clearly before us, we have been able to clearly formulate a whole series of preparatory individual problems, and to solve them one after the other. I can not go into details here. I will give but one example.

Obviously the usual mathematical methods will not be adapted to a problem of this sort. There can be no thought of an analytical presentation of the observational results with a subsequent analytical integration of the equations. As the observations are presented by means of charts, therefore all mathematical computations must be recast into graphical operations by means of maps. In this way we have developed for ourselves the rudiments of a graphical mathematics by means of which we derive one map from the other, just as one usually derives one equation from another by calculation. The steady development of the methods, which the novelty of our problem makes necessary, gives the work a peculiar charm which we would not forego. I hope that during my work here in Leipzig I may interest many younger colaborers in the abundant problems we meet with in this work.

Before closing I must touch upon an objection which is brought against our work. Our problem is, of course, essentially that of predicting future weather. "But," says our critic, "How can this be of any use? The calculations must require a preposterously long time. Under the most favorable conditions it will take the learned gentlemen perhaps three months to calculate the weather that nature will bring about in three hours. What satisfaction is there in being able to calculate to-morrow's weather if it takes us a year to do it?"

To this I can only reply: I hardly hope to advance even so far as this. I shall be more than happy if I can carry on the work so far that I am able to predict the weather from day to day after many years of calculation. If only the calculation shall agree with the facts, the scientific victory will be won. Meteorology would then have become an exact science, a true physics of the atmosphere. When that point is reached, *then* the practical results will soon develop.

It may require many years to bore a tunnel through a mountain. Many a laborer may not live to see the cut finished. Nevertheless this will not prevent later comers from riding through the tunnel at express-train speed.

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## PECULIARITIES OF THE CALIFORNIA CLIMATE.

### EXPLAINED ON THE BASIS OF GENERAL PRINCIPLES OF ATMOSPHERIC AND OCEANIC CIRCULATION.

By GEORGE F. McEWEN,

Oceanographer of the Scripps Institution for Biological Research.

[Dated January 5, 1914.]

### INTRODUCTION.

In the report on the scientific results of the Challenger Expedition, Buchan (1) concluded his discussion of atmospheric circulation with the following statement:

> The isobaric maps show, in the clearest and most conclusive manner, that the distribution of the pressure of the earth's atmosphere is determined by the geographical distribution of land and water in their relation to the varying heat of the sun through the months of the year; and since the relative pressure determines the direction and force of the prevailing winds, and these in turn the temperature, moisture, rainfall, and in a very great degree the surface currents of the ocean, it is evident that there is here a principle applicable not merely to the present state of the earth, but also to different distributions of land and water in past times.

In the present paper an attempt is made to show the effect of the difference in temperature between land and

water in modifying the distribution of atmospheric pressure and winds; and on the basis of these results, with the aid of Ekman's theory (**3**) of oceanic circulation, to account for the low-surface temperature along the west coasts of continents, special reference being made to the coast of California.

The contents of this paper fall under the following nine heads:

I. Preliminary explanation of atmospheric circulation on a non-rotating globe, and of the deflecting force due to the earth's rotation.

II. Ferrel's theory of atmospheric circulation on a smooth rotating spheroid.

III. Review of theories that have been proposed to account for the origin of the *ocean highs* (or areas of high air pressure on the ocean).

IV. A modified theory of the origin of the ocean highs.

V. Discussion of the causes of ocean temperatures either greater or less than the average for the latitude.

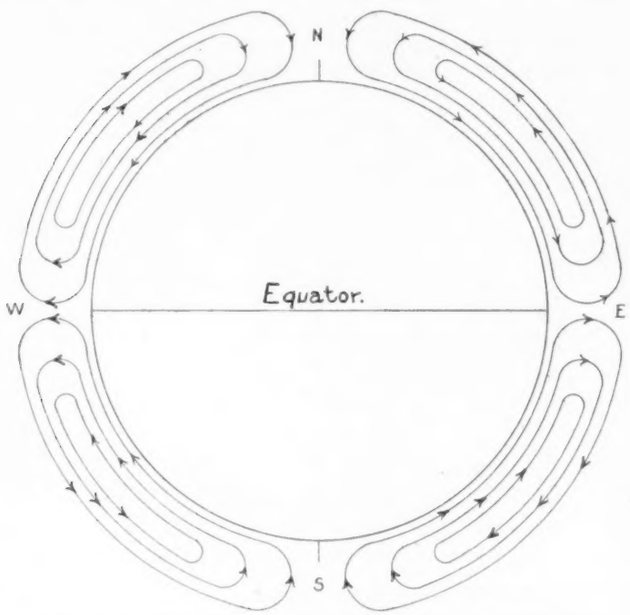


FIG. 1.—Condition of atmosphere under elementary hypothetical conditions.

VI. Ekman's theory of oceanic circulation, and its application to *upwelling*.

VII. The relation of winds parallel to a coast, the form of the bottom, *upwelling*, and surface temperatures off the coast of California.

VIII. Résumé and final applications of the preceding results.

IX. Summary.

## I.—PRELIMINARY EXPLANATION OF ATMOSPHERIC CIRCULATION ON A NON-ROTATING GLOBE, AND OF THE DEFLECTING FORCE DUE TO THE EARTH'S ROTATION.

Assume the earth to be a smooth non-rotating sphere, having a homogeneous surface [and that an] excess of temperature [is maintained] at the equator would expand the air, thus causing the upper part to overflow toward the poles. This removal of the upper air from the equatorial to the polar regions would decrease the pressure at the equator and increase it at the poles, thus giving rise to a return current of the lower air along meridians toward the equator. Thus there would be a steady circulation maintained by the action of the *pressure gradient* (**25**), against the frictional resistance, in which the horizontal area of upward convection would be approximately equal to that of the downward movement. Since half of the earth's area lies between the circles of latitude 30° north and 30° south, therefore these circles would divide the atmosphere into an equatorial region of ascending currents and two polar regions of descending currents. (See fig. 1.)

Ferrel (**6**) appreciated the importance in problems of atmospheric circulation of the tendency of bodies in motion to curve to the right in the northern hemisphere and to the left in the southern hemisphere. This tendency is a consequence of the *deflecting force due to the earth's rotation* (**6**); because of its frequent application to the problems in this paper, an explanation of the principle is given now.

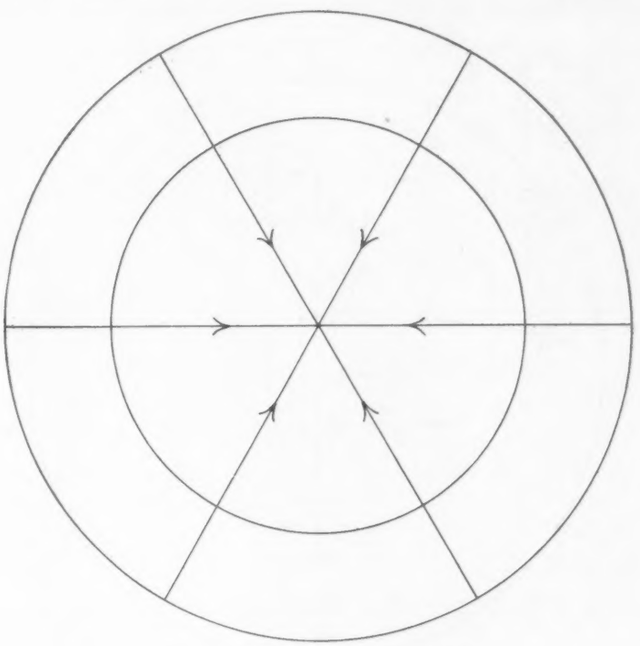

FIG. 2.—Gravitation and the ideal sphere.

Suppose the earth to be a plastic mass, homogeneous with reference to its center, and subject to the mutual gravitation of its parts. On the assumption of no rotation our planet would take a true spherical form, and the attractive force of gravity would act along lines through the center, and therefore perpendicular to any spherical surface having the same center. Under certain conditions the pressure would increase along a radius from the surface to the center, in order to balance the attractive forces. The sphere would then be called the figure of equilibrium of the earth, and its spherical boundary would be called a *level surface*, since the force of gravity would be perpendicular to the surface at each point (**26**).

Now suppose the earth to rotate about its axis **NS** (fig. 3). Then at each point of the mass an additional force would be required to maintain the spherical form. That is, in order to keep any particle **B** moving in a circular path of radius **BC** it would have to be continually pulled toward **C**, the center of the path; but if, at any time, both gravity and centrifugal force should cease to act upon the particle, it would continue to move with

a constant velocity along a straight line tangent to the circular path at that point.

In the case of the gravitating plastic globe, the only available force for holding the particles in their circular paths is gravity. Suppose this centripetal force **F** is subtracted from the force of gravity **G** leaving the effective, or apparent attractive force **G′**; then we must replace **G** by **G′** throughout. (See fig. 4.)

But **G′** would not be perpendicular to the original spherical surface, which would therefore not be level. Hence, the mass being plastic, the apparent or effective forces would so mold the sphere that its surface would be everywhere perpendicular to them, and the oblate spheroid shown by the dotted line **N′BE′S′** would result (fig. 4). The modification of the original spherical form would increase in proportion to the velocity of rotation and the plasticity of the mass, thus to each velocity of rotation would correspond a different figure of equilibrium.

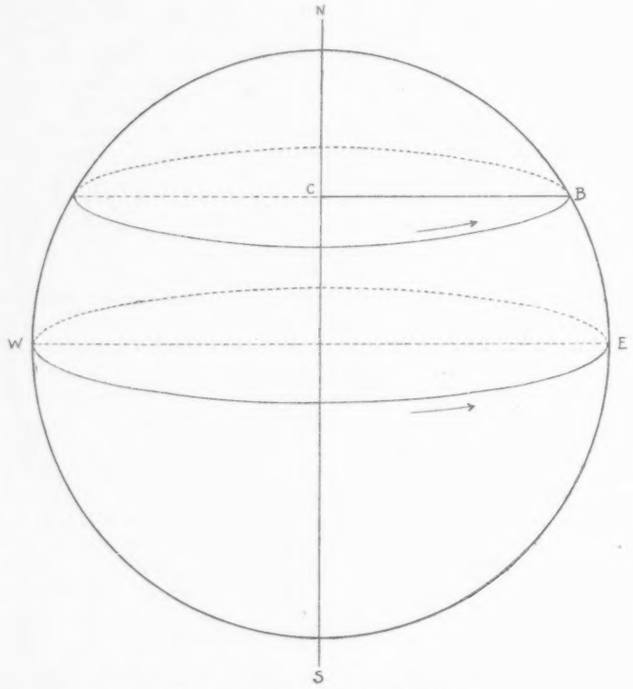


FIG. 3.—The earth, a rotating spheroid.

Neglecting comparatively slight irregularities of its surface, the earth is an oblate spheroid, corresponding very closely to the figure of equilibrium which would result from its present angular velocity: for many theoretical purposes it may be regarded as a true spheroid having a homogeneous surface. A particle at rest on such a rotating body would be in equilibrium.

But if the particle was forced to slide along the surface, for example to the east, an additional force perpendicular to the axis **NS** (fig. 4) would be required to hold it in this circular path, since its actual velocity in space would be greater than that of the earth's surface for that circle of latitude. If this force was subtracted from the apparent force of gravity **G′**, the resulting force would have a component tangent to the earth's surface and directed toward the equator, as can be seen by reasoning as before. While if the particle was moved to the west it would be forced toward the pole.

From another principle of mechanics, the *conservation of areas*, the effect of the earth's rotation on motion along a meridian can be determined. According to this principle, a line from a moving particle perpendicular to the earth's axis will describe equal areas in equal times as it rotates, unless a force not passing through the axis is applied. In other words the product of the actual eastward velocity of the rotating particle **B** (fig. 3) by its distance **BC** from the earth's axis must be constant [unless] a force acts on the particle in an east or west direction. Hence, when a particle on the earth's surface is forced toward the nearest pole **N** or **S**, the velocity to the east must increase, while if forced in the opposite direction the eastward velocity must decrease, since in the first case the distance from the particle to the axis is decreasing, while in the latter case it is increasing.

The above results may evidently be reduced to the following rule: Whenever a body moves along the earth's surface it becomes acted upon by a force directed to the right of the motion in the northern hemisphere, as shown by figure 5, but to the left in the southern hemisphere.

Analytical mechanics shows that the magnitude of this deflecting force ($2\,\omega\,v\sin\theta$) is proportional to the velocity

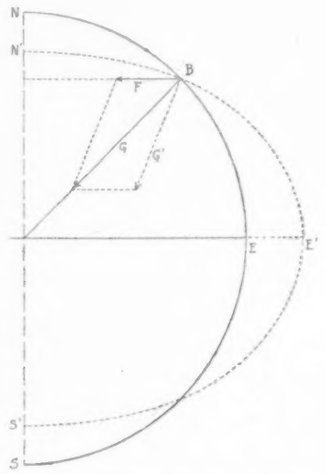


FIG. 4.—Gravitation and centrifugal force.

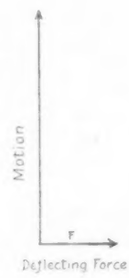


FIG. 5.—Constrained motion on the surface of the rotating spheroid.

of the body, and increases with the latitude, from zero at the equator to a maximum at the poles.

## II.—FERREL'S THEORY OF ATMOSPHERIC CIRCULATION ON A SMOOTH ROTATING SPHEROID (27).

The general scheme of atmospheric circulation obtained by averaging the observed wind velocity for each of a series of parallels of latitude is shown by figure 6, while the distribution of pressure (28) obtained in the same way is represented by figure 7. The latter diagram represents a vertical section of the atmosphere by a plane through a meridian, which, for convenience, is represented by the straight line **N E S.** Each curve shows the relation of the pressure to the latitude at the elevation indicated on the right.

Now, by means of the two great facts on which this motion depends, namely, the relatively high equatorial temperature and the deflecting force due to the earth's rotation, we can explain the main features of atmospheric circulation and pressure distribution. The upper air over the equator tends to overflow along the meridian

toward the poles, owing to the expansion due to the heated surface below, but in the northern hemisphere the overflow is deflected to the right, and were there no friction, would move to the east in a direction perpendicular to the meridional barometric gradient, which would then balance the deflecting force. But, since the air is a viscous fluid this motion to the east, if started, could not continue owing to the frictional resistance, which would decrease the velocity and therefore the deflecting force. The air would then be forced to the north because of the unchanged pressure gradient. Therefore, because of friction, the air actually moves to the north of east with such a velocity that the deflecting force and the resistance are in equilibrium with the gradient.

Thus the upper air moves spirally from the equator toward two poles with a relatively large eastward component, owing to the comparatively small amount of friction in the upper layers. Also as the distance of the air

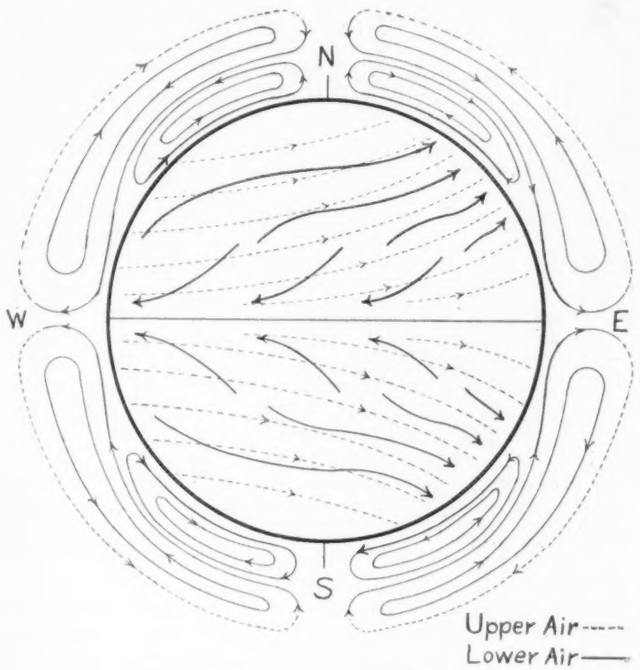


FIG. 6.—Ferrel's scheme of atmospheric circulation.

from the earth's axis decreases owing to the poleward motion, the eastward velocity must increase.

Most of the air leaving the equator must return in an undercurrent at various intermediate latitudes. Only a small share can complete the entire circuit. Also, we would expect the horizontal area of the region of upward convection to be approximately equal to that of the downward movement; thus the upward motion would extend from the equator to about latitude 30° north and south, while the remaining area, from each parallel of 30° to the poles would be a region of descending currents.

The strong equatorward deflecting force due to the high eastward velocity, serves to carry the air of intermediate elevations from the polar regions toward the equator, against the comparatively weak gradients of that region. This intermediate current continues its eastward motion until it passes the latitude of 30°, from which it moves obliquely backward (to the west) and reaches the earth's surface, becoming the northeast trade wind.



As the earth's surface is approached, the eastward velocity of the air, between latitudes 30° north and the north pole, and between 30° south latitude and the south pole, decreases because of friction to such an extent that the deflecting force is overcome by the poleward gradient and the lower air moves spirally eastward and toward the poles, becoming the prevailing westerlies.

The opposing thrusts of these winds on opposite sides of each circle of latitude 30° causes the high pressure zone along those circles, because of the deflecting force.

The low pressure at the polar regions results from the general eastward motion of the air at all latitudes and elevations outside of the zone from 30° north and 30° south. The equatorward deflecting force due to this eastward whirl reduces the amount of air in the polar regions and heaps it up toward the high-pressure zones.

Thus, this mechanical effect reverses the gradient that otherwise would result from the relatively low polar temperatures.

It is important to bear in mind that in the above rea-

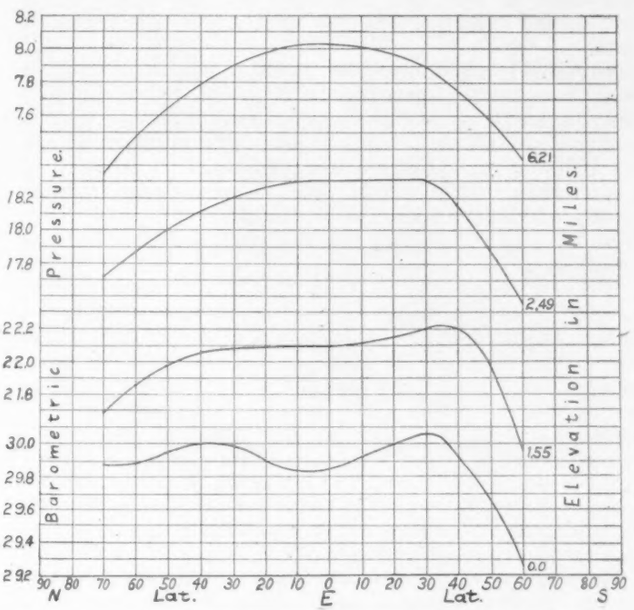


FIG. 7.—Ferrel's scheme of the distribution of pressure with elevation and latitude.

soning, which is a brief qualitative reproduction of the most important part of the elaborate investigation made by Ferrel, the earth was assumed to be a smooth rotating spheroid.

## III.—REVIEW OF THEORIES THAT HAVE BEEN PROPOSED TO ACCOUNT FOR THE ORIGIN OF THE OCEAN HIGHS.

A detailed examination of the pressure distribution along parallels of latitude shows a systematic variation in pressure; meteorological charts representing yearly averages show five oceanic high-pressure areas. One is in the Indian Ocean, about half way between southern Africa and Australia; two are off the west coasts of North America and northwest Africa, at latitude 35° north; the other two are off the west coasts of South America and southern Africa, at latitude 32° south.

Humphreys (**10**) says: "There is, necessarily, a close relation between the location and intensities of these ocean highs and the weather of the adjacent continents,

and therefore they deserve careful study. But while they themselves and their results are more or less discussed in works on meteorology, it appears that, in spite of their importance, but few attempts have been made to explain their origin."

According to Ferrel (**7**), a portion of the west to east winds of the higher latitudes is deflected toward the Equator by continental barriers, and thereby forced to join at each of these places the counter winds within the Tropics, producing the anticyclonic whirl on the adjacent ocean. He attributes the high pressure at the center of each whirl to the effect of the deflecting force due to the earth's rotation, and disregards the effect of temperature differences.

But, as Humphreys (**10**) says, the barometric high in the South Atlantic can not be accounted for on the barrier hypothesis, as the west to east winds of the southern hemisphere pass to the south of Africa in January and February. Again, if thermal causes are not a factor in producing the high pressure, it must follow that the surface winds would have an inward and the upper winds an outward velocity, which is contrary to the observed facts.

Angot (**11**) attributes the highs to the fact that on every parallel between the latitudes of 45° north and south, the average surface temperature of the continents is higher than that of the oceans. The pressure within the belts of highs where the atmospheric pressure is greater than that on either side is lowered over the continents and raised over the oceans, thus explaining why these belts have pressure maxima with closed isobars on the oceans.

But as Humphreys (**10**) says, this theory would appear to call for anticyclonic centers not far from mid-ocean, though rather nearer the largest continent. We would also expect those of the northern hemisphere to be more pronounced than the corresponding highs of the southern hemisphere, because of the greater differences in temperature due to the extensive land areas of the former. But observations show the highs to be of equal intensity in both hemispheres, and to be located near the western coasts where, for some distance inland the continents are not so warm as they are on the eastern side, which is contrary to the requirements of his theory.

Humphreys (**10**) calls attention to the fact that the oceanic highs are located in the high-pressure belts near the west coasts of continents, the centers of the highs being separated from the coasts by cold ocean currents. He holds that—

> The cold surface water, because of the limited amount of heat it supplies, whether by radiation or conduction, allows the air above it to cool to a correspondingly low temperature, and for any given pressure to contract and grow denser. This decreases the pressure at considerable elevations above the cold surface and allows the air to pour in from all sides, which in turn so raises the pressure at the surface of the ocean that there is a tendency for the air to flow out in all directions at the lower levels.
>
> Hence, where this cold current crosses a belt of high pressure at about 35° north or 32° south, there are two cooperating causes of high pressure: (*a*) The opposing thrusts of eastward and westward winds, as explained in Ferrel's theory of atmospheric circulation (**5**), causing a high-pressure zone and a calm belt parallel to the Equator; (*b*) a sheet of cold water crossing this high-pressure zone from the polar to the equatorial side, which by virtue of the cooling, increases the high at the place of crossing, and thereby produces a highest center with closed isobars and gentle anticyclonic winds.

He explains the location of the centers of the highs, which are west of the point of minimum temperature of the ocean, and therefore of the air also, by the changed direction of the winds over the coldest areas.

> Because these winds have but little east or west motion, they fail to give mechanical support to the ridge of highs, which, therefore, in part gives way at this place.

## IV.—A MODIFIED THEORY OF THE ORIGIN OF THE OCEAN HIGHS.

Owing to certain objections to Humphreys' theory, I have developed a modified form of that proposed by Angot (**11**) in which the difference in temperature between continental and oceanic areas is regarded as the controlling factor. First let us review briefly the contrast between the land and the ocean upon which this difference in temperature depends (**12**).

The ocean reflects more solar radiation than the land, and is comparatively transparent, while the land is opaque, therefore the energy not reflected from the surface of the ocean is absorbed throughout a considerable depth, each layer receiving but a small fraction of the total, while a comparatively thin upper layer of land absorbs most of its incident radiation. Moreover, the land is not volatile, and therefore dry soil does not cause a disappearance of much energy as heat of volatilization, but great quantities of ocean water, by evaporating, remove a large proportion of the radiant energy received by it.

There are several other factors that combine with those mentioned to reduce both the annual and the diurnal temperature variations of water areas much below that of land areas. For example (**14**), the range of the annual surface temperature (**29**) is less than 6° over the oceans in the Torrid Zone, and less than 11° over the oceans in the greater part of each Temperate Zone, while in the surface air over the corresponding land areas the ranges are two or three times greater.

Now on the basis of Ferrel's theory (**5**) and the consequences of these differences between the physical properties of land and water, let us [investigate] the origin of the high off the California coast. In winter the temperature of the continent is less than that of the ocean, whereas in all seasons (**13**) the average wind velocity over the land is about one-half of that over the ocean. Thus the mechanical effect of the east and west components of the winds in producing a high-pressure belt is greatest over the ocean, while the difference in temperature tends to increase the pressure on the land and reduce it on the ocean.

These facts account for the approximately uniform distribution of pressure along the parallel of 35° in winter (**1**). But in summer, when the continents are warmer than the ocean, there must be an overflow of the upper air from the former to the latter, thus causing a decrease of pressure over the land and an increase over the ocean. Since as [in the] winter the relatively greater wind velocity in an east and west direction over the ocean operates in the same way, we would expect high pressure over the ocean having closed isobars.

Now if the temperature difference were the only factor considered we would expect, as Humphreys (**10**) said, to find the center of this high midway between the continents. But, owing to the prevailing eastward drift of the upper air (**8**), from which the descending current over the high is supplied, we would expect this downward current to have a general eastward motion as well. Thus there would be a tendency to form an anticyclonic whirl having a maximum pressure at its center, but displaced eastward toward the west coast of North America, as the charts of pressure distribution show.

The mean [wind] velocity perpendicular to a given meridian is a maximum for a meridian through the center of the high and decreases as the meridian is displaced either to the east or to the west. This is partly because the winds of the anticyclonic whirl blow to the east, north of the center and to the west, south of the center, so in each case they tend to increase the average east or west components of the general atmospheric circulation. Another reason is that the average velocity of the oceanic wind decreases toward the land to about half of its original value. There may be, as Ferrel (7) suggested, a deflection of the west wind along the coast of North America, which would cause an additional reduction of the east and west components, as the coast of California is approached. Therefore we would expect the transition from the east and west components over the ocean to their comparatively low values on land, to be more gradual toward the coast of Asia than toward the California coast only one-third as far away. These conclusions are confirmed by the charts made by Buchan (1).

The cold water bordering the California coast would tend to cool the superincumbent air and thus increase the pressure gradient near the coast, where the difference in temperature between the surface water of the ocean and the surface of the land is comparatively great. This conclusion is also verified by the same charts, and by observations made since they were prepared.

Owing to the extensive areas contributing to this convective circulation, we would expect an immense volume of air to descend to the ocean and form an anticyclone of a corresponding area. This conclusion is also supported by observations, judging from the magnitude of the areas inclosed by the closed isobars, Buchan (1).

We should also expect the center to be displaced farther from the coast as the volume of descending air increases, because of the larger area required at the bottom of this air column which must terminate at the surface of the ocean. This conclusion is verified by the fact that in summer the center is 800 miles farther from the coast than in winter. (See Buchan Chart 1.)

From the same charts, the latitude of the center of the North Pacific high, and the corresponding pressure and temperature were found, and compared with the mean pressure and temperature over a narrow belt of the same latitude in Asia and North America, for each month. The result shown by Table 1 indicates, as required by the above theory, that the pressure difference increases and decreases with the temperature difference.

TABLE 1.—*The relations between temperature and pressure.*

| Month. | Temperature over— | | Pressure over— | | Differences. | |
|---|---|---|---|---|---|---|
| | Land. $t_1$ | Ocean. $t_2$ | Land. $p_1$ | Ocean. $p_2$ | $t_1-t_2$ | $p_2-p_1$ |
| | °C. | °C. | *Inches.* | *Inches.* | °C. | *Inches.* |
| January | 12.7 | 18.3 | 30.19 | 30.15 | − 5.6 | −0.04 |
| February | 12.0 | 15.0 | 30.14 | 30.20 | − 3.0 | + .06 |
| March | 17.0 | 17.2 | 30.06 | 30.25 | − 0.2 | + .19 |
| April | 20.3 | 16.1 | 29.95 | 30.30 | + 4.2 | + .35 |
| May | 22.5 | 16.1 | 29.87 | 30.30 | + 6.4 | + .43 |
| June | 28.0 | 16.7 | 29.80 | 30.30 | +11.3 | + .50 |
| July | 29.50 | 18.3 | 29.78 | 30.30 | +11.2 | + .52 |
| August | 28.0 | 17.2 | 29.80 | 30.30 | +10.8 | + .50 |
| September | 23.0 | 14.4 | 29.95 | 30.30 | + 8.6 | + .35 |
| October | 21.1 | 16.9 | 30.07 | 30.15 | + 4.2 | + .08 |
| November | 11.4 | 15.6 | 30.16 | 30.20 | − 4.2 | + .04 |
| December | 8.6 | 12.8 | 30.17 | 30.20 | − 4.2 | + .03 |

The relation between $(p_2-p_1)$ and $(t_1-t_2)$ of the above table can be approximately expressed by the equation,

$$(p_2-p_1)=0.155 \text{ inch}-0.031(t_1-t_2),$$

which shows that even when the difference in temperature is zero centigrade, the pressure exceeds that over the land by 0.155 inch. This excess, which amounts to about one-third of the maximum difference in pressure, may be accounted for by the facts that the wind velocity over the ocean surface is about twice as great as over the land surface in all seasons, and that the oceanic west wind is turned aside from its eastward course by the California coast, which acts as a barrier.

## V.—DISCUSSION OF THE CAUSES OF OCEAN TEMPERATURES BEING EITHER GREATER OR LESS THAN THE AVERAGE FOR THE LATITUDE.

Let us now examine briefly the circulation and temperature of the oceans, mainly for the purpose of accounting for the presence of the cold-water regions mentioned before. Wherever the temperature of the ocean water differs notably from the average of that latitude and depth, local disturbing factors must be present.

An abnormally high ocean temperature might be the result of a flow from a warmer region; or, again, the concentration of the heat due to solar radiation, in a relatively thin layer of water might cause an abnormally high local temperature. But for depths exceeding about 100 meters the latter effect is insignificant, since nearly all of the solar rays are absorbed by that depth of water (15).

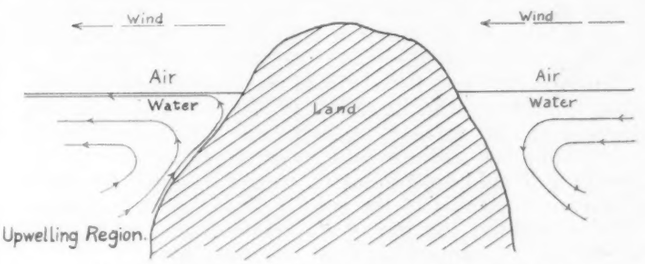


FIG. 8.—Off-shore winds and upwelling cold water. On-shore winds and warmer water.

An abnormally low temperature might be due to melting ice brought down from the polar regions, or to a current of water from a colder region. It is generally admitted that cold currents may either flow horizontally from a colder region along the surface or along any other level, or [that] they may rise from lower levels where the ocean temperature is always less than the normal for the surface at the same latitude.

The latter type of circulation is denoted by the term *upwelling*, and several examples of both kinds of circulation have been observed. Moreover, there is no general agreement as to which type, in some regions, is of the most importance or as to the cause of either.

A review of the literature shows that most authorities agree in accepting winds blowing offshore as a sufficient explanation of cold water along the west coasts of continents. Figure 8 shows how offshore winds may, by mechanically removing surface water, cause an upwelling from the bottom, and thus lower the surface temperature. Some authorities believe the cold inshore water to be the combined result of the above cause and of polar surface

currents, while others regard the latter as the only cause (**2**, **16**, **17**, **18**, **19**).

But the hypothesis of offshore winds requires an extension of the trade-wind belt greatly beyond its observed limits, where calms or even on-shore winds prevail (**20**).

While polar surface currents may in some instances contribute toward these cold belts, their presence in other cases is inconsistent with the observed distribution of temperatures. For example, there are instances in which warm water extends for considerable distances in all directions from a cold inshore region. While there are other cases in which strips of alternately warm and cold water lie in a direction perpendicular to the supposed polar current (**21**, **23**).

Each of the above explanations of the cold water along the west coast of North America is open to one of these objections (**21**, **23**).

In order to avoid the above objections, Holway (**21**) assumed that in the northeastern part of the Pacific the drift to the east was true not only for the surface of the ocean but all the way to the bottom. Thus the cold deep water would be driven up the slope of the bottom toward the continental shelf, the effect being greatest near Cape Blanco, Oreg. (latitude 42° 50′), owing to the neighboring submarine valley. This upwelling would account for the cold surface water. However, his hypothesis does not account for the alternately warm and cold water found at various places along the coast at least as far south as latitude 28°, nor does it explain the large seasonal variation of the cooling effect (**22**, **23**).

Thorade (**22**) concluded (from observations on the seasonal change in the direction of the wind and on the changes of the surface temperatures off the California coast) that the inshore cold water must be due to the upwelling of cold bottom water, caused by the component of the wind parallel to the coast. This, he said, is inexplicable without the use of a modern theory of oceanic circulation, developed by V. W. Ekman (**3**).

From the complexity of the phenomena which may produce the low temperatures, it is likely that in any given case a correct explanation can be worked out only by detailed observations of the main factors and by the application of physical principles.

## VI.—Ekman's theory of oceanic circulation and its application to upwelling.

I shall now discuss briefly a part of the recent theory of oceanic circulation developed by V. W. Ekman (**3**). Although a detailed explanation of this theory involves complex problems in mechanics and mathematics, the main features of it can be given qualitatively in the following elementary manner:

Suppose a wind is blowing horizontally over the surface of a body of water, then the water will move under the action of three forces (**W**); that of the wind acting in a direction toward which the wind blows (**D**); that of the deflecting force due to the earth's rotation (see p. 16); and (**R**) [that due to] the friction of the water underneath which opposes the motion. Hence the resultant surface velocity of the water (V) will be directed to the right of the wind in order that the three forces (Fig. 9) may be in equilibrium. This surface layer of water will act upon the one underneath, just as the wind acts upon the surface layer, and so on downward. The mathematical theory shows that if we neglect differences in density, and also the influences of neighboring ocean currents and continents, the motion will correspond to the following diagram (Fig. 10). The following description may help in visualizing this motion. Imagine a spiral stairway so situated that the edge of the top step is directed at an angle of 45° to the right of the wind velocity, thus coinciding with the arrow $V_o$ of Fig. 10. Now if, as we descend, the successive steps are shortened so as to have

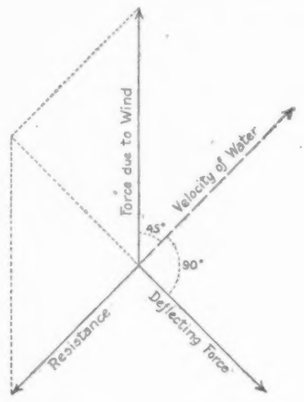


FIG. 9.—Three forces that determine the velocity of the surface water.

in succession, the lengths of the arrows in the diagram, the [length] of [each] will represent in magnitude and direction the velocity of the water at that depth. And by the time a half turn had been made the edge of the step, that is, the velocity of the water would be only 4 per cent of its value $V_o$ at the top, and from there downward

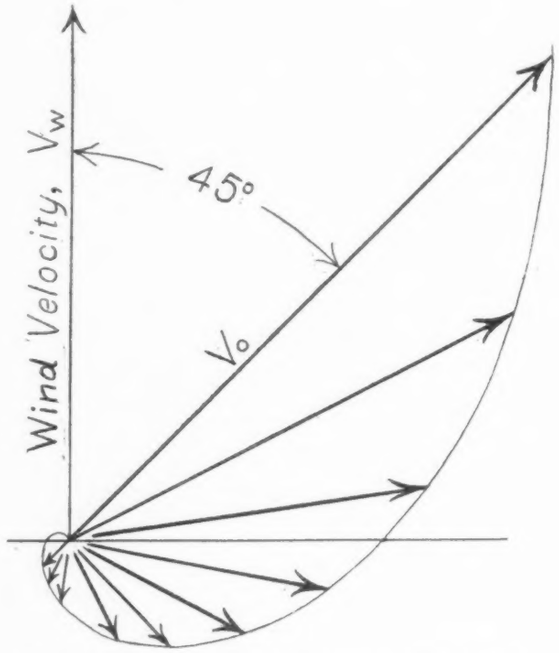


FIG. 10.—The direction and velocity of the water at increasing depths.

we would find the velocity to be still smaller. So, for practical purposes, we can neglect the motion below that point. This depth increases with the wind velocity, but decreases with the latitude. For example, at latitude 35°, if the wind velocity is 10 miles per hour, the depth (**30**) would be about 45 meters.

Suppose the wind has a component parallel to the coast line, and the water lies to the right when looking in the direction of that component. According to the previous theory, surface water will be carried to the right of and along the coast, thus causing a depression of the water level there. The corresponding reduction in pressure below the surface would cause a flow of bottom water toward the coast and upward to the surface. Thus the surface water that flows away from the coast would be continually replaced by water upwelling from the bottom (Fig. 11). Also, owing to the pressure gradient directed toward the coast, there would be a flow parallel to the coast at all depths.

In the above discussion it was assumed that the depth of the water [exceeded] about twice the depth of the wind current (**31**) and that the coast was vertical. As the depth decreases from that value the effect of the wind becomes less modified by the deflecting force, and the motion takes place according to commonly accepted laws, to which Ekman's more general theory reduces when the water is sufficiently shallow. If the coast was but little inclined from the bottom, the breadth of the upwelling region would be much greater and the vertical velocity would be proportionately reduced.

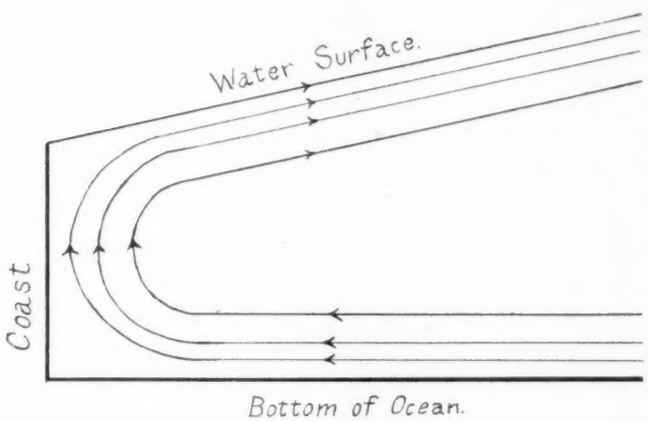


FIG. 11.—Upwelling of ocean water.

## VII.—THE RELATION OF WINDS PARALLEL TO THE COAST, THE FORM OF THE BOTTOM, UPWELLING, AND SUFACE TEMPERATURES OFF CALIFORNIA.

In a former paper (**23**) I obtained, with the aid of Ekman's theory, a mathematical relation between the wind velocity, the surface temperature of the inshore water, and the normal for a given latitude.

The following table showing the data used and the results obtained, for a belt of water extending west from San Francisco, indicates the agreement between the theoretical and observed temperatures. The formula derived for this region is

$$T=(1-0.030\,V_w)t_2+0.030\,V_w t_1,$$

in which—

$T$ is the surface temperature of the inshore water, $t_2$ is the normal surface temperature for the latitude, $t_1$ equals 8°, the mean temperature of the upwelling water (centigrade), and $V_w$ is the component of the average wind velocity in miles per hour parallel to the coast line over an area whose center is about 400 kilometers from the coast. All of the variable quantities correspond to the same month.

| Month. | $V_w$. | $t_2$. | Calculated $T$. | Observed $T$. | Differences. |
|---|---|---|---|---|---|
| | *Mis./hr.* | °C. | °C. | °C. | °C. |
| January | 7.70 | 14.20 | 12.80 | 12.50 | 0.30 |
| February | 6.87 | 13.80 | 12.60 | 11.60 | 1.00 |
| March | 9.25 | 12.60 | 11.30 | 11.50 | −0.20 |
| April | 11.40 | 12.00 | 10.60 | 11.30 | −0.70 |
| May | 12.50 | 14.50 | 12.10 | 11.30 | 0.80 |
| June | 14.40 | 15.20 | 12.10 | 13.80 | −1.70 |
| July | 17.50 | 20.00 | 13.70 | 13.50 | 0.20 |
| August | 18.60 | 19.90 | 13.25 | 13.00 | 0.25 |
| September | 17.60 | 19.90 | 13.60 | 13.80 | −0.26 |
| October | 13.60 | 18.10 | 14.30 | 14.60 | −0.30 |
| November | 8.80 | 16.60 | 14.30 | 13.90 | 0.50 |
| December | 6.65 | 15.20 | 13.80 | 13.40 | 0.40 |

Since the upwelling is more concentrated, the more rapidly the depth increases with the distance from the coast, we would expect the reduction of the surface temperature to be correspondingly greater. Also, we would expect the temperature to increase along a horizontal line running out from the coast. Both of these conclusions agree with the results of observations off the California coast (**23**).

## VIII.—RÉSUMÉ AND FINAL APPLICATIONS OF THE PRECEDING RESULTS.

The results of the preceding investigation may be condensed into the following eight propositions:

1. The west winds (**32**) north of latitude [35° north] press southward, while the east winds, south of the same parallel, press to the north, because of the deflecting force due to the earth's rotation.

2. The side thrusts of these winds give rise to a belt of high average air pressure between the east and west winds, at latitude 35°, but the average wind velocity is about twice as great over the ocean as over the land; also, the west wind is deflected partly to the north and partly to the south, by the west coast of North America.

3. Thus the mechanical effect of the winds in producing the high air pressure is always greater over the ocean than over the land.

4. In summer there is an overflow of the upper air from the warm land surface to the comparatively cool surface of the ocean, while in winter, when the land is colder, this circulation is much weaker, or may even be reversed.

5. Therefore, in summer, the mechanical and thermal causes combine in producing a high-pressure area over the Pacific Ocean, and low pressures over the continents of Asia and North America; but in winter the mechanical and thermal causes are opposed, thus giving rise to an approximately uniform pressure along the circle of latitude 35°.

6. Because of the prevailing eastward drift of the upper air from which the descending current (over the Pacific Ocean) is supplied, the center of the high-pressure area is displaced to the east, but remains far enough from the west coast of North America to allow the descent of the immense volume of air to the ocean. The distance from the center to the coast varies from 800 to 1,500 miles.

7. Because of the spiral motion of the air outward from this center, and the southward deflection of a portion of the west winds, there is a broad belt of northwest winds along the California coast. The velocity of these winds is greatest in summer and least in winter.

8. These winds produce an upwelling of the bottom water adjacent to the coast at a rate proportional to their

velocity parallel to the coast, thus cooling the surface and causing a general drift to the southwest of this surface water, whose temperature is lowest at the coast and increases from there with the distance from the coast.

From the above propositions we see that the periodic cooling of the inshore water off the coast of California is caused largely by the Pacific high-pressure area, whose intensity depends upon the varying heat of the sun through the months of the year, and upon the difference in temperature and wind velocity due to the contrast between land and water surfaces.

Let us now consider some of the objections to Humphreys' theory of the origin of the ocean high off the California coast. The area of the California cold-water belt (**23**) appears to be too small to produce the large area of high air pressure shown by observation (**1**). The center of the high is 1,500 miles west of the region of minimum

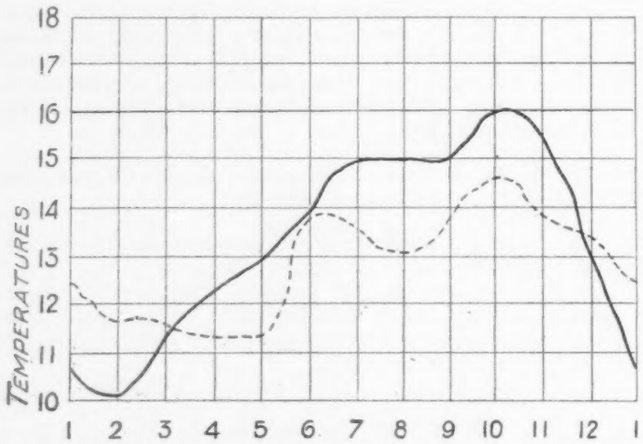


FIG. 12.—Cool summers at San Francisco controlled by adjacent ocean temperatures. ..... ocean temperatures, ——— air temperatures.

temperature in summer, while the maximum width of the cold-water belt scarcely exceeds 1,200 miles (**1**, **23**). But the main objection is that the upwelling theory just explained shows that the existence of the sheet of cold inshore water depends upon the coast winds, which in turn are largely due to the Pacific high. Therefore the sheet of cold water which Humphreys claims is the cause of the [North Pacific] high is really one of its effects.

An inspection of the charts (**1**) showing the average monthly pressure, wind velocity, and temperature of the world indicates that the other three highs and cold-water belts may be accounted for by a theory similar to the one just applied to the North Pacific ocean. And, judging from the results already obtained, the general problem of ocean highs and cold-water belts is a profitable field for further investigation.

On the California coast, the prevailing wind over the land blows from the west of north except during a part of the winter. We would expect from this fact that, between the ocean and the mountains, the climate, except possibly in winter, would be largely controlled by that of the adjacent surface water of the ocean. The observations represented by figures 12 and 13 verify this conclusion, at least as far as temperature is concerned. Thus the well-known cool summers at the California coast are due largely to the cold inshore water, whose low temperature is indirectly caused by the relatively hot continental areas of Asia and North America.

## IX.—SUMMARY.

1. The uniform high-pressure belt along each of the circles of latitude 32° north and 35° south, which would be formed if the earth's surface were homogeneous, is actually broken up into several areas of relatively high and low pressure.

2. This break in the continuity of pressure is partly due to differences in the physical properties of land and water areas, which give rise to an unequal temperature distribution along parallels of latitude, the land being the warmer [area] in summer and the cooler one in winter. Also, the relatively high east and west components of the wind velocity over the ocean, as compared to those over the continents, tend to cause a continual excess of pressure on the ocean over that on the continents.

3. Barometric observations over Asia, the North Pacific ocean, and North America show that the above difference in wind velocity combines with the seasonal temperature differences between the ocean and the land in such a way as to produce an approximately uniform high-pressure belt along the parallel of latitude 32° in winter, while in summer the cooperation of the mechanical and thermal causes gives rise to a high with closed isobars over the ocean.

4. The periodic variation of the intensity of the North Pacific high gives rise to an extensive periodic anticy-

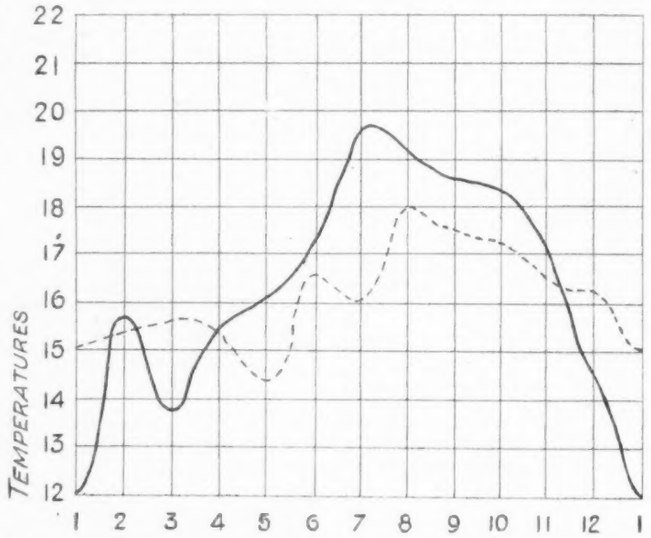


FIG. 13.—Cool summers at San Diego due to cold on-shore winds. ..... ocean temperatures, ——— air temperatures.

clonic whirl off the California coast, of which the prevailing winds blowing from the west of north, along the coast, are a part.

5. These winds produce an upwelling of cold bottom water along the coast at a rate proportional to their velocity parallel to the coast, and thus reduce the surface temperature of the inshore water sufficiently to produce the well-known cold-water belt off California.

6. The climate of that part of California lying between the coast and the mountains is largely controlled by the surface temperature of the adjacent ocean, and consequently agrees at any place with the normal marine climate of that latitude in winter. But in summer, when the upwelling is so pronounced as to reduce the surface

temperature of the inshore water much below the normal, a coast climate, peculiar in many respects, is produced, the remarkably low summer temperature being the most striking peculiarity.

7. Thus the "Egyptian winters and Alaskan summers" (**24**) experienced in San Diego are explained as a necessary consequence of the operation of physical laws in connection with the distribution of land and water areas, hence the stability of the climate of San Diego is comparable with the stability of the present geological features and astronomical configuration.

In conclusion, I wish to thank Dr. W. E. Ritter and Mr. E. L. Michael for their suggestions relative to the presentation of the subject in a form comprehensible to the general reader, and Mr. C. J. Marvin, of the Scripps Institution, for his assistance in making the drawings.

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(**25**) The *pressure gradient* or *barometric gradient* is the rate at which the pressure decreases in going a unit distance horizontally along a level surface from a place of high to one of low atmospheric pressure, or vice versa.

(**26**) Under these conditions, a plumb line would coincide with the earth's radius produced through the point of suspension.

(**27**) The trade-wind theory advanced by George Hadley (**9**) required a steady increase in pressure from the equator to each pole, according to the observed decrease in temperature. But barometric observations taken from 1839 to 1843 (**4**) contradicted this theory, and the general problem of pressure distribution and atmospheric circulation remained inexplicable until Ferrel developed his theory of atmospheric circulation during the period from 1856 to 1882.

(**28**) Atmospheric pressure is expressed in inches of mercury throughout this paper.

(**29**) The centigrade scale of temperature is used throughout this paper.

(**30**) The general relation is $D$ (in meters) $= \frac{3.4}{\sqrt{\sin L}} W$, where $L$ is the latitude and $W$ is the wind velocity in miles per hour.

(**31**) Wind-current is a technical term used to denote the current in the upper part of the water, produced by a wind under the conditions assumed on p. 20.

(**32**) The wind blows *from* the direction named.

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## LORIN BLODGET'S "CLIMATOLOGY OF THE UNITED STATES": AN APPRECIATION.

By ROBERT DE C. WARD.

[Dated, Harvard University, Cambridge, Mass., Sept. 22, 1913.]

So impossible is it to keep our heads above the rising tide of the new meteorological literature that we are neglecting, to our loss, the rich stores which lie buried in the books of a generation ago. The name of Lorin Blodget is probably known to Americans chiefly through their reading of the sections on the United States in Dr. Hann's *Handbuch der Klimatologie*, where the ranking meteorologist of to-day makes appreciative reference to, and quotation from, the work of our pioneer American climatologist. Yet Blodget's discussion was of fundamental importance, and is, even now, worthy of the attention of all our students of climatology.

During the short semi-vacation of the past summer, spent among the New Hampshire hills, I have turned again to Blodget's *Climatology of the United States* for relaxation and for instruction. More than ever before, I am impressed by the labor involved in the preparation of this book; by the author's broad and clear view of his subject; and by the practical application of the facts. My rereading of this book has given me new light on my path as a teacher. And I hope that this notice may turn attention once more to the importance of Blodget's work for American climatology, and may help to preserve for this almost forgotten author of 50 years ago the place to which he is entitled among American meteorologists.

It was no easy task which Lorin Blodget set for himself.[1] It would have discouraged many men. But Lorin Blodget did it. And he did it well. No one else has attempted, much less carried through, so ambitious an investigation. Gratefully, and gracefully, does our author acknowledge his indebtedness to Alexander von Humboldt, whose "models were his guide" and whose "tone of generalization" it was Blodget's "highest ambition to attain." Out of the confused mass of scattering observations which had been accumulating from different sources at the Smithsonian Institution and the Office of the Surgeon General, and from "gentlemen at distant points distributed over the country," Blodget brought

[1] The full title of the book is as follows: "Climatology of the United States, and of the Temperate Latitudes of the North American Continent: Embracing a full comparison of these with the Climatology of the Temperate Latitudes of Europe and Asia, and especially in Regard to Agriculture, Sanitary Investigations, and Engineering, with Isothermal and Rain-Charts for each Season, the extreme Months, and the Year. Including a Summary of the Statistics of Meteorological Observations in the United States, condensed from recent scientific and official Publications." (Philadelphia, J. B. Lippincott & Co.; Trübner & Co., London, 1857. xvi, [17]–536 p. 4°.)

order and accuracy so far as was then possible. Clearly recognizing the necessary inaccuracies in his results, although "great care had been taken to correct and verify the records," Blodget realized that they "would still have great practical value in engineering, agriculture, and sanitary investigation." It might perhaps be well, to-day, if less time and money were sometimes spent in the effort to insure the highest possible accuracy of our records before we begin to make *practical* use of them. We may well believe that the work of our author "was prosecuted with excessive labor," and that "no part of the present work * * * is the result of hasty or superficial discussion." The practical features of American climatology were foremost in his mind throughout, "in part for the reason," as he clearly saw, "that a research in this new department of physics must commend itself to economical interests or fail to be sustained." With these practical objects in mind, Blodget planned his book along lines which must commend themselves to the preeminently practical spirit of our own times. A teacher of the climatology of the United States might do much worse than follow, as an outline, the chapter headings of Blodget's volume.

The keynotes of the book are struck in the *Preliminary Chapter*—the advantages of the longer series of European records; the importance of a knowledge of the climates of the interior and of the West "from the point of view of climatological adaptation to occupation by populous States;" the "symmetry of arrangement" in the climates of Europe and of North America. It is surely practical climatology at its best when we learn that "the cultivation and productive capacity of England may be reproduced on the Pacific here, and all the vast systems of industrial, commercial, and social results which follow in the train of such conditions." Of the magnitude of his undertaking Blodget was painfully conscious. Each division of his subject, he wrote, "requires a volume rather than a chapter," and "for all taken together" it is "such as it is scarcely possible for one person to make." In the early fifties a total of 583 stations in the United States—of 639 in temperate latitudes as a whole—gave a considerable foundation upon which to build. This was the material upon which Blodget based his conclusions, and which he laboriously collected and summarized. His *Summary* includes several of our historical long-period records, such as that for Charleston, S. C., from 1738; Boston and vicinity from 1780; and New Bedford, Mass., from 1812. The broad and essential topographic features which control our climate are described under the suggestive chapter heading, *Climatological Features of Surface and Configuration*. Special emphasis is laid upon the uniformity of surface and of climate over the eastern United States, where, in spite of the mountain masses of Appalachians, Adirondacks, and White Mountains, "the forests and *general climate* remain as before." [2]

Those—and there are many—who believe that local topography produces local climates *essentially different* from the general conditions of the surrounding country may well remember Blodget's statement just quoted: The *general* climate remains. "We scarcely regard the Alleghenies," he says, "as disturbers of any condition of climate except in the moderate degree produced by altitude alone, as they are ascended." In the Rocky Mountains "climates with great extremes of temperature necessarily follow" from the plateau character of the topography, and the Pacific coast mountains, though they occupy but a narrow space, "shut off the basins of the interior as effectively as if a great distance and many ranges intervened." The expression *climatological topography* (p. 101) seems to me particularly significant and worthy of extended use. A sharp insight into the relative conditions in Eurasia and in North America is indicated in the contrast between the presence of "deserts and Asiatic features at the first eastern foot" of our Pacific coast mountains, while similar climates do not appear in Eurasia for "50 degrees of longitude of a climate ranging from oceanic or maritime." Blodget's clear reasoning regarding the existence of prevailing westerly winds over the temperate latitudes is well worth quoting:

> In proof that such a belt exists the difference of temperature of the opposite coasts of both [North America and Eurasia] seems a conclusive evidence. If no atmospheric circulation modified this distribution by conveying the heated or refrigerated air in some direction, there is is no reason for any such difference as we find to exist. The maximum of continental effect in refrigeration and aridity should be found in the center of the continent, and its degree should be as great on the west as on the east.

In a later chapter the trend of the isotherms and the difference in temperature and in humidity on the opposite sides of the continent are also taken as evidence of the prevailing westerly winds. While our Great Lakes do locally modify some of the extremes of continental climate, they are themselves the product of abundant rains, and "could not exist if extreme continental features of climate were ever fairly developed there." In other words, the Lakes modify the climate, but exist because the climate *is* modified!

This is a striking statement, and it is true. In a discussion of the *General Character of the Climate of the Eastern United States* [3] we find many of the larger climatic characteristics set forth as clearly as they have ever been presented, before or since. The continentality of the Atlantic coast climate, with its slight marine modifications, is admirably described by stating that on the immediate coast "a local oceanic climate exists, *but it is always blended with the continental features* which belong to this part of the continent generally." In his general summary for the eastern United States Blodget says:

> The principal feature of this area as a whole is its adaptation to a great range of vegetable and animal life. It is extreme without being destructive, and it brings in tropical summer temperatures and profusion of rain with low winter temperatures, near to those of the extreme continental climates; and the result is a condition extremely favorable to the acclimation of tropical or semitropical plants and animals. * * * It is simply an excess of temperature and of humidity, *engrafted on, without otherwise changing, the characteristic laws elsewhere belonging to much lower temperature.* * * * Cotton, Indian corn, and the cane find their natural climates here, but not elsewhere, in any considerable degree, beyond the Tropics.

Over all this eastern area, cyclonic weather changes—"oscillations of every sort," Blodget calls them—are "symmetrical and uniform." The expression *paroxysms of change*, used for the sudden shifts characteristic of the passage of cyclones, especially in winter, seems to me very fitting. The increase of temperature in front of an approaching cyclone, "of duration proportioned to the measure of the change that is to occur"; the explanation of the more emphatic development "of the last phase" of the cyclonic "circuit" by reference to the general atmospheric movements from the west, "with which this phase of the change coincides, and *to which it is superadded*"; the sympathetic allusion to the prevailing summer wind as "the soft, pleasant, peculiarly American wind, with a finely variable force"; the recognition of the "patchy" occurrence of frost when it is referred to "as though dropped from the atmosphere"—these are but a few

[2] The italics here and in later quotations are mine.—R. DEC. W.

[3] Chapter III.

of the interesting points contained in this chapter. At the end are some notes on occurrences of severe cold, as valuable to-day as when they were compiled. On the severe winter of 1780 we read that Washington sent troops aross "an unbroken body of solid ice" to attack the British on Staten Island, and on February 6, 1786, sleighs were sent over the ice with provisions for the troops.

A good working knowledge, if it may be so called, of the climatic characteristics of the interior may be gained from Blodget's summary.[4] The "absence of atmospheric moisture" is noted; "sensible perspiration is rarely experienced in even the warm climate of southern New Mexico," and "the languor and oppressiveness attending a heat of 90° to 95° in the eastern States is never felt at such temperatures"; and the dry winter cold of the interior is more easily borne than damp cold. Practical results of the low relative humidity are seen in the fact that "the valuable grasses" dry "without loss of their nutritive qualities," and the "absence of humidity" is also "very favorable to observation of astronomical and other instruments." Periodic, diurnal controls are dominant, while changes "of what may be called the greater nonperiodic sort" distinguish the east. "Extreme contrasts, diversities, and transitions belong here [in the interior] to *place*, or *locality*, and in the east to *time*." This is a significant summary.

A live *Comparison of the Arid and Interior Areas* of North America and of Eurasia, based on selected descriptions, illustrates very well how vivid a picture of climate can be drawn without endless tables of numerical data and without even a single curve.[5] Similarities in modes of life are emphasized and predictions regarding the future climatological capacity of North America are made. "There is no climatological reason," says the author, "why the Rio Grande, Gila, and Colorado Rivers should not be lined with spots of rich, half-tropical cultivation, like the Tigris and Upper Indus." Blodget lived to see at least some of his prophecies fulfilled.

Even the most enthusiastic resident on our Pacific slope will be satisfied with Blodget's reference to "the elastic atmosphere and bracing effect" which "constitutes a striking difference from those of the Eastern States."[6] There is no climate on the slope " which is not the reverse of enervating. * * * All residents concur in pronouncing it more favorable to physical and mental activity than any they have known, from whatever quarter they come." I know of no briefer yet more comprehensive and suggestive climatic comparison than this, that "the Pacific coast climates are Norwegian, English, and Spanish or Portuguese, with the intermediate France blotted out." The general character of the storms, of the onshore winds and of the fogs at San Francisco, is described in well-chosen quotations from Dr. Gibbons (pp. 196–198), who gave us, years ago, graphic accounts of Pacific coast weather phenomena which have lost nothing by the passage of time. The easterly storms of the Atlantic climates, Dr. Gibbons says, are unknown there. "In almost every month of the year, even during the dry season, the clouds *put on the appearance of rain* and then vanish. It is evident that the phenomena which produce rains in other climates are present in this, but not in sufficient degree to accomplish the result, except during the rainy season, and then only by paroxysms with intervening periods of drought." Where can we find any more graphic account of San Francisco's summer than in Dr. Gibbons's description which ends: "In short, there is no conceivable admixture of wind, dust, cloud, fog, and sunshine that is not constantly on hand." "It is unfortunate," Blodget continues, "for the productive capacity of that side of the continent that the mountains are so near the coast, and that the climate changes so soon in consequence"—a sentiment with which most of us cordially agree.

In a further comparison of Europe and North America,[7] when Blodget says of Vancouver Island that "the whole climate, indeed, is peculiarly soft, equable, and *English*," he gives one an admirably condensed and accurate statement. The charts (isothermal and isohyetal) are obviously long out of date, but the critical comparisons made by our author are worth attention. He emphasizes an important *practical* climatic fact when he says that "the local influence of the icy region of Hudson Bay reduces the cultivable capacity by cooling the summer." And his comparison of western European and eastern North American climates is worth quotation.

> From Europe as a standard, the American climate is singularly extreme. * * * The oscillation of the conditions is greater, and they vibrate through long measures above and below the averages. All the irregular as well as regular changes are of this sort, and the European observer defines the climate as directly antagonistic to that he has left.

As a general description of seasonal weather types in the eastern United States, where have we anything more sympathetic, or more vivid, than the following?

> In summer the whole area of the United States is * * * occupied by this predominating feature—the irregular distribution of profuse showers alternating with entire serenity. Nowhere else are thundershowers such grand and conspicuous phenomena, occurring at intervals on successive days, and with a stately and almost orderly distribution over great belts of country. In the Northern States they are more constant than in the Southern, or more likely to occur on the afternoon of every day through the warmest month or months, while at the thirty-fifth to the forty-second parallel they usually occur in belts, continuing even two or three days, and embracing a district equal to that from St. Louis to Philadelphia; this belt or period to be succeeded by one entirely serene, of equal extent and duration. * * * There is no feature of climate more attractive than this constant succession of the showers of summer in the middle and northern latitudes of the United States. * * * Periods of excessive heat and saturation, of two to five or eight days' duration, are common in the American summer, and quite characteristic of it. * * * These warm periods continue over several days also, and if the air is dry the temperature readily rises to about 100°. If saturated, or nearly so, it rarely goes above 95°, but the effects are very destructive in these cases, great mortality occurring in the cities from "sunstroke."

Our author says:

> As the summer advances, the intervals of dry weather usually increase in duration, and in the early part of autumn these several periods are sometimes of 15 days' duration. * * * West of the Lakes, or of Lake Erie, the rain in autumn rapidly diminishes, and the long, dry, smoky intervals occur in their most complete development. * * * Where the autumn does not differ largely from the quantity of rain at other seasons, as in New England and farther northward, there are still intervals of the serene and beautiful weather so prevalent on the plains. The popular designation of *Indian summer* is universal, and it is held certain that one such period, of some days' duration, will occur in October of every year. * * * It is here clearly nothing more or less than smoke and vapors suspended in an atmosphere of unusual quiet. * * * The prevalent winds in the United States are from the west, and after the heats of summer immense areas of dry grass of the plains are constantly burning. This smoke is wafted eastward, and in the light atmosphere it descends, filling the surface air sometimes so much as to give it a stifling closeness.

Then quoting from Drake's description of Indian summer in the region about Cincinnati, Blodget proceeds:

> The atmosphere during its continuance is tranquil, temperate in heat, and hazy; but not much obscured by clouds. Falls of rain are,

[4] Chapter IV.
[5] Chapter V.
[6] Chapter VI. *Distinctive features of the Pacific Coast Climates.*
[7] Chapter VII. *General Comparison of the Temperate Climate and of the Eastern United States with the West of Europe.*

however, not uncommon; and in general the whole appearance breaks up with a rainstorm, followed by a winter temperature. An apparent smokiness through which the sun and moon, when near the horizon, and especially at evening, appear of a crimson hue, is the great characteristic of the season.

The chilling northeast winds [of the eastern United States, Blodget points out] are distinguishingly American. * * * On the New England coast the sea influence is always great, and local mists with chilling sea winds prevail very much at certain seasons. The northeast wind is the natural storm wind of all this coast, attending all the general storms as a persistent phenomenon of two or three days' duration. * * * It is felt on the plains beyond the Mississippi, at the head of Lake Superior, and in Texas not less decidedly, though less frequently and of less duration, than on the coast of New England. But in the last locality it bears the ocean scud and mist with it, and produces an extremely chilling effect at all seasons.

Concerning winter weather types we may quote the following:

The piercing and violent northwest winds which follow a storm or a period of warm weather appear colder, or are felt to the senses as colder, than the thermometer would indicate; and the intense cold of winter in the interior is not so uncomfortable as it is in Boston, although the thermometer may fall many degrees lower. The Atlantic coast is one of almost constant atmospheric disturbance, or the conditions vibrate in one direction to return immediately through the same range. There are none of the "dead calms" which exist in the interior of continents in winter as well as in summer. * * * It is the most decisive proof, perhaps, of the extreme character of the American climate in comparison with the European, that the snows of winter are thrown so far south and into latitudes where the summer heats are tropical.

The expression *thrown*, for the cyclonic effects in carrying snow far south seems a particularly happy one.

The smaller area of the subtropical belt in North America than in Europe often puzzles younger students. On this point our author clearly says[8]:

If the Gulf of Mexico were similar in position to the Gulf of California, yet extended inland like the Mediterranean, the districts of the various local peculiarities now bordering on the Mediterranean would be reproduced. * * * The space where we may look for phenomena correspondent to those of the Mediterranean is here relatively very small.

The unfavorable effect upon crops of the "nonperiodic extremes of cold occuring at distant intervals" along the borders of the Gulf of Mexico is emphasized. This is one of the marked, and, economically, one of the most unfortunate, climatic characteristics of the eastern United States.

Much of Lorin Blodget's best pioneer work was done in the construction and discussion of his seasonal and annual temperature and rainfall charts, in which he took pardonable pride.[9] The details are naturally out of date, but there is reference to many *general* facts of importance to-day. For example, we are reminded of the parallelism of summer isotherms and the Pacific coast, giving "almost absolutely equal temperature" along this coast, while off the Atlantic coast the lines "double on themselves abruptly;" the remarkable uniformity of summer temperature over the interior; the occurrence of the winter minima to the west of the Great Lakes, "the point of natural minimum" being "broken up" by the lakes, whose location is "most fortunate for the cultivable districts of this part of the United States;" the diminished warming effect of the Gulf of Mexico waters in winter owing to the "great relative refrigeration of the continent, generally and the consequent prevalence of land winds" (i. e. offshore), and the similar condition along most of the Atlantic coast, where, "if the prevalent winds were reversed, the climate would be *greatly softened*." Blodget lays none too much emphasis upon the remarkably favorable conditions of summer rainfall over the Mississippi Valley. "There is no great area so far in the interior," he says, "which presents a similar result."

In the discussion of the winds[10] the relation between temporary cyclonic and permanent westerly winds is clearly recognized, and the Texas monsoons are called by that name,[11] their cause is indicated and their climatic consequences are appreciated. The section on winter storms[12] brings out some of the results of Blodget's laborious study of these phenomena. He constructed, in all, some 50 or more "elaborate charts * * *, so as to give successive panoramic views, as they may be termed, of the whole country at a definite hour." Variations of temperature and pressure from the mean; winds; and cloud and rain areas, were shown on these charts. Several expressions are worth remembering. The change to a rainy spell is usually inaugurated by "a south or southeast wind, with high temperature and a *palpable sense of preparation*." This *palpable sense of preparation* we have all of us noted time and again, but no one else has described it in such a vivid way. The expression that as our storms advance the northeast winds in front "*recede eastward*" is also a striking one. That cyclones move along isotherms is also seen. In regard to the origin of our cyclones, "they originate in changes of the measures of heat and moisture introduced from exterior sources, and * * * these changes are absolutely nonperiodic and can not be foretold." A good many meteorologists of the present day might find this a fair statement of their own views.

Three chapters (XIII–XV) deal with the "climatological range" of forests and of certain crops and grasses. This eminently practical matter is often omitted from climatological discussions, which therefore lack the vivid and essentially human quality. But Blodget was keenly alive to all the practical aspects of his subject. The "primarily climatological" control of our forests and the need of "accurate climatological distinctions" in dealing with the distribution of our native and cultivated plants is vividly brought to the reader's attention. The term *climatological capacity*, which Blodget uses, seems a singularly happy one. It expresses, briefly, what we generally try to define by means of a lengthy circumlocution. A point of practical importance concerns the use and making of hay:

As a whole, the American climate is singularly favorable to the making and preservation of hay or dried grasses—the natural hay of the plains being unparalleled indeed. The long winter in the Eastern States requires a much larger preparation of hay than the English climate, and the summer is much more favorable than that of Europe for this preparation.

The historical background of Blodget's times is clearly seen in the discussion of the relations of climate and health.[13] Military posts in "newly acquired territories" in the South and West were then kept "at the exterior limits of settlements in all cases, as the control of the Indian tribes required." Thus were the early records begun by the Medical Corps of the Army. Thus were laid the foundations for the medical climatology of the United States. Such a statement as this, "that India itself has not been more certain to break the health of the emigrant than the Mississippi Valley," shows how crude and unreliable was the medical and climatic knowledge of those days a generation ago. The disappearance of malaria and of yellow fever with the cold, and the prevalence, in their place, of "the forms originating in the sharp temperature changes of the cold zone," are

[8] Chapter VIII.
[9] Chapters IX and X.
[10] Chapter XI.
[11] "Something very near a monsoon."
[12] Chapter XII.
[13] Chapter XVI.

accurately noted, as is the fact that great variations of temperature and humidity in a climate generally cool and damp afford the conditions most extremely favorable "for pulmonary tuberculosis." One other point, which deserves constant attention in all our statistical studies of medical climatology to-day, is this:

> Large numbers seek milder climates and perish there, whose cases should be set down to the country from which they came.

A chapter (XVII) on the *Permanence of the Principal Conditions of Climate* is appropriately included. A summary of the literature, so far as it was known to him, is given by the author. "For the whole of the vast historic period," he says, "there have been the same deserts in Africa and Asia, the same absence of water in the rocks and soil." As to the evidence for and against climatic "change," our author rightly holds that "real history would be more valuable than anything else if it could be relied on, but there is great looseness with much exaggeration in everything dating back beyond the use of instruments." Blodget believes that "the Northmen found the New England coast 860 years ago quite precisely the same in climate as now—wild vines growing in a very few of the most favored spots, and only in these." In Iceland and Greenland he finds no evidence of a change of climate; only a change in the conditions of people and of government. Dr. Hugh Williamson is quoted as saying, in 1770, that the winters of the last half century had been milder than formerly, and Prof. Samuel Williams, of Harvard College, whose lectures were among the foundation stones of American meteorology, asserted that "the winter is less severe, cold weather does not come on so soon." These views sound singularly like many that we hear expressed in 1913. For Europe and Asia authorities are cited, and the need of accurate observations, extending over long periods, is clearly recognized. The dates of the breaking up of ice in Russian rivers are given back to 1530.

In a section on *Physical Constants* [14] various temperature and pressure data and curves and some meteorological tables are given. Finally, at the end, in a discussion of the climate of the Northwest,[15] Blodget stands out as preeminently a *practical* climatologist. How crisp, clear, confident, and encouraging is his assertion made, we must remember, before the days of our western railway network; before the great waves of population had rolled over the West; before systematic and well-directed observations were available for all this region—that "it is impossible to doubt the existence of favorable climates over vast areas now unoccupied."

It is thus that I wish to conclude this appreciation of Blodget's *Climatology of the United States*, hoping that what I have written may refresh the memories of those who already know the book, and may stimulate others to turn to the original for the inspiration which no reviewer can hope to give.

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## IS THERE AN AURORAL SOUND?

By JOHN OXAAL, Christiania.

[Translated by Julius C. Jensen from the reprint from "Naturen," April, 1913.]

The northern or polar lights have from the earliest of times, by reason of their prominence in the polar night, attracted the attention of man and compelled him to examine and study them. When it now chanced that science undertook their investigation there remained certain attendant phenomena which defied all explanation. I have in mind a phenomenon in regard to which there have always been sharply defined differences of opinion, which, after all, can perhaps be scientifically explained.

It is this: Are strong auroral displays accompanied by sound? What kind of a sound is this? Under what conditions does it occur? Reports of distinct crackling noises in connection with strong, flaming auroras are almost numberless, but, so far as is known, this sound has has never been observed by those expeditions which have been sent out for the express purpose of studying the aurora, although there are many accounts in which other scientists purport to have heard it.

Sophus Tromholt made a long series of systematic observations of the aurora, and in old files of Naturen are found various discussions by him; but although his attention was directed especially to the question of the auroral sound, his investigations led to no affirmative results in regard to it. Haakonson-Hanson also made careful observations of a similar nature in Trondhjem, but heard no sound. However, it ought to be pointed out that a city is not a favorable location for observations of this kind.

Among the rank and file of the people a strong belief prevails that such a sound actually exists. How general this belief really is appears in an article in Naturen for the year 1892. In consequence of this belief Sophus Tromholt, in 1885, sent out questions concerning both the aurora and the auroral sound, to a large number of those interested in the subject in all parts of the country. Out of 143 who answered, no less than 56, or about 36 per cent, testified to having heard the sound themselves.

It is not merely scientists who, in the course of time, have applied themselves to this problem, and since in most cases the investigations have given a negative result, it is hardly to be wondered at that the numerous accounts which have come mostly from laymen should be regarded with skepticism. It must be remembered that the aurora belongs to that class of phenomena which tends in the highest degree to arouse the imagination. Is it not possible that one may be so influenced by the sight of a gloriously flaming, rapidly shifting aurora, playing in colors of sheerest blue, red, green, and violet, while rays of light suddenly shoot out and disappear again, as to imagine that one actually hears at the same time a crackling, rustling sound? Bearing this in mind, it is perhaps not unreasonable that one should have been led to question the word of scientists who, on other occasions, have shown themselves to be keen and sober observers, and thus have come to regard the whole phenomenon with doubt.

Under these circumstances I believe each individual observation may have a significance, and I will therefore set forth the following:

On a trip to the most northerly part of Finland, in the autumn of 1911, I remained for some time 2 or 3 miles [1] south of Lake Enare. On returning to my hut after the day's work on October 10, while my Finnish guides were preparing supper I witnessed the most beautiful auroral display I have ever seen. Several parallel bands, now two, now three, which alternately united and divided, streamed across the sky from the west through the zenith to the east. They were in constant wave motion, one instant slow and deliberate and the next swift and impetuous, while rays of light darted out from them and disappeared again.

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[14] Chapter XVIII. [15] Chapter XIX.

[1] Norwegian miles. One Norwegian mile equals 7 English miles.

On the northerly side the bands were of a reddish-violet hue while on the southerly, now bluish, now yellowish-green. The colors were repeated in each band.

Little by little the aurora lost its strength and I sat down to supper. Some time after—unfortunately I can not tell the exact instant—I heard in the north a peculiar, even insistent, rumbling noise not unlike distant thunder. It was so characteristic that I jumped up to see what was going on. The aurora appeared like a bow in the north. It struck me at once that this must be the much-talked-of mysterious auroral sound, and in order to make sure of it I asked my two attendants if it proceeded from the aurora. They replied in the affirmative and continued their work as if it were a well-known and common occurrence.

We may attribute the sound to other causes, but it will be difficult to find a satisfactory one. The air was calm; so it could not have been the soughing of the wind in the forest nor the sound of falling trees. It was 5 miles [2] to the nearest inhabited place toward the north and south, 2 toward the northeast, and several to the post road. It is not likely that any travelers were abroad at this time of the night in the winter's cold. A river flowed past our camp on the south. Its noise could be heard constantly, but it was even, continuous, and of a different character.

I wrote Mr. Waenerberg, superintendent of mines in Thule, west of Lake Enare, to ascertain whether or not the sound had been heard there. He has a long record of meteorological observations, at least 30 years in length, made for the Finnish Meteorological Institute, and is a very careful observer. He replied as follows:

> On October 10, 1911, we had a very beautiful, flaming aurora over the whole dome of the sky, but no sound was heard here. It is when the aurora sinks down low over field and forest that it is accompanied by a noise similar to that of a roaring and rushing stream. Four times in 34 years have I observed this sound and reported it to various observatories, of which Mr. Tromholt's is one.

It is 60 to 65 kilometers from my camp to Thule; so it is not at all unlikely that the sound might be heard at one place and not at the other. Again, it is specially noteworthy that this reliable observer also states he has heard auroral sound, but according to his experience it is seldom so pronounced as to be heard generally.

I might again remark that while the aurora flamed and played in the most brilliant hues no sound was heard.

Another phenomenon which I observed at the same time ought to be mentioned as it probably has some connection with the sound heard. As remarked above, the display gradually decreased in strength. The wave motion became weaker, the definite boundaries disappeared, and the illumination became more general. The sky was quite clear before the appearance of the aurora. After a little, light clouds began to form near the zenith where the aurora had been. The transition, which seemed quite uniform, was peculiar to observe and at a certain point it seemed difficult to determine whether the faint light proceeded from the last rays of the dying aurora or from the fine, light, newly formed cirrus clouds.

According to Prof. Störmer's measurements the aurora's average height above the surface of the earth is 150 km., and therefore much greater than the maximum height of the lightest cirrus clouds. Is there, then, any connection between the aurora and the cloud formation mentioned, has it in this instance dipped down much farther into the atmosphere than usual and is it perhaps only under these conditions that a sound phenomenon accompanies it? Superintendent Waenerberg's observation, that it is only when the aurora settles down low over the fields that it produces a sound, would seem to confirm this conclusion.

I have examined some much earlier works on the aurora in order to ascertain whether or not the older reports contain any accounts of the auroral sound, and shall set down what I have found.

I mentioned above an extract from Naturen, 1892, concerning answers which Tromholt had received in regard to this phenomenon. This article was the result of a discussion in the Chicago Skandinavien in the autumn of 1892. Several persons had there positively asserted that they had heard the sound themselves while others expressly denied its existence. So, in several other old files of Naturen we find reports of the auroral sound, viz, in those of 1880, 1883, and 1885.

Tromholt's large catalogue of auroral observations in Norway up to 1878, published by Schroeter, has numerous discussions of this subject. The earliest, and in some respects rather unreliable, account is that of Absalon Pederssön, dated December, 1563. This recital is so amusing that I will repeat it here:

> One evening a little before Christmas I witnessed the following occurrence which began about 7:30 and continued until fully 9 p. m. Christern Ulff and a goldsmith and both their wives and servants saw it also. At first the moon shone clear in the east. Then a dark cloud which reached high up into the sky came over it. Presently a bright cloud, which shone like a white flame, formed and both remained stationary for some time. After they disappeared an unusually black cloud with scattered cloud wisps all about it approached from the south and overshadowed the moon so that it lost its light. After it had passed the sky grew red in the west and fire and flame darted back and forth so that a great noise was given off. I asked Christern Ulff what caused the sound, as I thought perhaps it came from the Alreichstadselff.[3] He replied, "Don't you see it is in the sky? It was the clouds that ran rapidly back and forth." Afterwards other clouds, some black and some white, overcast the moon and then disappeared.

On January 18, 1778, Dean Wilse of Spydeberg thought he heard the auroral sound.

However, in the large catalogue which contains reports of thousands of auroras, there are few instances of this sound recorded. On March 22, 1840, Ihle observed an aurora in Kaafjord which, according to his report, was accompanied by a peculiar noise. Ihle was a naturalist and has himself given an account of his observations which has been published. He is reported to have heard the sound on two other occasions during the same winter.

It is also reported to have been heard following marked displays in Okso on no less than four different occasions in the course of two and one-half years, viz, September 7, 1851; February 19 and April 21, 1852; and February 24, 1854. But Okso lies far out toward the sea, and even if the reports are true they can not be given much weight since the observations were made in such exposed places.

Sophus Tromholt, who devoted almost his entire life to the study of the northern lights and who has written much in regard to them, has published in the Proceedings of the Videnskapsselskapet for 1880 a paper on the auroral sound which contains many interesting recitals. One of the most interesting of these is perhaps one from Dr. Follum, of Alten, who writes:

> Once, in November, 1856, on Beskades, a mountain ridge between Alten and Kautokeino nearly 1,500 feet above sea level, on the occasion of an exceptionally brilliant aurora with gleaming rays of light shooting out from the crown I heard a peculiar, faint, crackling noise in the sky. My companion heard it also and I remember distinctly having stopped and remarked on the sound.

A more extended report by Tromholt's father, "a skillful and reliable meteorological observer about whose

[2] Norwegian miles.

[3] A river near Bergen.

trustworthiness there can not be the slightest doubt," is of great interest. He purports to have heard the sound three times in all and says that he is sure it could not reasonably be attributed to other causes.

The following contribution from Pilot O. J. Dahle (pilot on the *Haakon Adelsten*) dated March 30, 1910, was furnished me through the courtesy of Prof. Störmer:

> Eight or nine years ago I witnessed from the steamship *Erling Jarl* an extraordinarily interesting aurora. While our ship was crossing Vaags Bay, a little north of Harstad, a brilliant aurora in rapid motion was seen so low down in the air that it barely cleared the tops of the masts. It flamed forth in all the colors of the rainbow and was followed by a peculiar sound, precisely such a sound as would be produced by rubbing together a well-dried skin in the hands. It was neither imagination nor the mistaking of any sound on board, but undoubtedly the result of the movement of the aurora. I have noticed also on other occasions that auroras in rapid motion hanging low in the atmosphere have emitted sounds similar to those mentioned above.
>
> In the above-named display it seemed that the auroral rays had a horizontal position and appeared as separate layers, one above the other. But the probability is that it was a vertical ray which, by reason of its nearness and its position directly over the ship, appeared to to us to be horizontal and that the higher layers were the movements of the same ray seen through this identical ray from below.

The Finnish physicist, Lemström, has written a work entitled "The Polar Lights." Here also are several accounts, one by a miner from Göteborg who was in Lapland in 1842. He describes an aurora observed at night in midwinter in a temperature of − 45° C. A band of rays streamed up from the plateau between him and adjacent peaks and "a rushing sound could at the same time be plainly heard."

The well-known French balloonist, Rollier, who with an attendant ascended from Paris in 1870 during the siege and came down in Lifjeld , Telemarken, reports that he observed polar light rays through the light fog and, "presently a peculiar rushing sound was heard. A short time after, strong, almost suffocating fumes of sulphur were encountered."

Lemström himself, according to his own report, has never heard the auroral sound, but he specifically states that he is convinced of its existence, and this assertion is repeated several times. He speaks of the Laplanders' firm belief in the sound in the following language:

> They say that a rumbling sound can often be heard and since it has frequently been observed by skilled observers, their belief that it actually exists in connection with strong, energetic auroras at low temperatures is absolute.

In a work by Prof. Hermann Fritz of Zurich, in 1881, concerning the polar lights, there is also collected from all sources a great number of accounts of the auroral sound. Upon examining these we come across many well-known men, even eminent scientists, who believe in the existence of this sound, for instance, Prof. Hansteen. We find also in this book various old Norwegian reports.

One would think since so many well-known and highly esteemed men have given such indisputable evidence of having heard the sound that all doubt would gradually be dispelled. But this is so far from being true that, on the contrary, many scientific men, for instance, the famous explorers, Leopold von Buch and Alexander von Humboldt, assert unqualifiedly that it is nothing but imagination. Humboldt says the native population knows nothing of the auroral sound and that it is the transients who have brought the belief with them. But this is a singular misapprehension of the facts, for the belief is especially widespread among the natives. "The polar lights have grown more taciturn," says Humboldt, "since we have learned to observe them more closely," and that is quite possible, for there are probably numerous false reports of the auroral sound, especially those that report it as audible at the time the lights are most active and vivid, for it requires a certain time in which to traverse the distance to the observer.

On the other hand it is not always when the aurora drops down moderately near the earth that it can be heard. There are numerous accounts of the polar lights which, judging from the observers' descriptions, have been very near the surface of the earth and which according to these descriptions have not been accompanied by any sound.

In a work on the height of the aurora by Cleveland Abbe in Terrestrial Magnetism, 1898, are cited a great number of reports of such displays which have been seen against the mountains and hence very near the earth, as for instance, that of the well-known polar explorer, Parry. Sir William Hooker saw the same phenomenon at Ben Nevis, Scotland. General Sabine observed an aurora that was so low that it lay like a fog over the ground, through which he walked. Galle, the famous astronomer, saw a cloud growth following an aurora and also a display very similar to that which I observed in Finland, and I cite Galle's observations here because the account of such a man surely ought to be given great weight. It seems therefore incontrovertible that the aurora, under certain conditions, may reach down into the atmosphere at least to the altitude of the cirrus level, approximately 6,000 meters.

EDITOR'S NOTE.—In a letter from the author, dated Christiania, November 27, 1913, he adds:

> * * * It will perhaps interest you to hear that the only Norwegian member of the Scott Antarctic Expedition, Mr. Trygve Gran, once heard a peculiar noise attending an Aurora Borealis [i. e., Aurora Australis] and Mr. Gran also told me that the party of Lieut. Campbell had repeatedly heard such a noise.

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## THE METEOROLOGICAL ASPECT OF THE SMOKE PROBLEM.[1]

By HERBERT H. KIMBALL.

### THE ATMOSPHERE AND ITS CONTENTS.

*Atmospheric gases.*—The terrestrial atmosphere consists of a mixture of gases that may be divided into two quite distinct classes: (1) The elementary gases, such as nitrogen, hydrogen, oxygen, and the gases of the argon group; (2) the compound gases, such as vapor of water, ammonia, ozone, carbonic acid gas, etc.

The gases of the first group are practically fixed in amount with respect to one another at any given level (**1**), while those of the second group are constantly varying not only with respect to the atmospheric conditions, such as temperature, pressure, and humidity, but also with respect to place. This is especially true of gases generated in the processes of combustion, which may be almost unknown in thinly inhabited districts, but which have to be taken into account in the atmospheres of large cities (**2**).

The gases of the atmosphere hold in suspension considerable quantities of solid and liquid particles. The latter consist principally of condensed water vapor, forming fog and clouds, which may hold in solution substances of various kinds, including some acids, as has been shown by numerous analyses of rain water and snow. The solid particles may be divided into several

[1] Condensed, with additions and revision, from Smoke Investigation Bulletin No. 5, Mellon Institute of Industrial Research and School of Specific Industries, University of Pittsburgh, 1913.

classes, such as cosmical or meteoric dust, finely divided mineral matter or soil from the surface of the earth, pollen from plants, microscopic organisms such as bacteria and molds, and the soot and other residues of combustion.

*Atmospheric dust.*—Much of the dust consists of particles so fine that, as Barus (**3**) states, it may be considered "an integrant part of the atmosphere." Meteoric dust is of this character, and Young (**4**) has estimated that the amount received by the entire atmosphere probably can not exceed 100 tons per day, which would produce a covering an inch thick on the surface of the earth only after the lapse of 1,000,000,000 years.

Humphreys (**5**) has suggested that certain observed sudden changes in the positions of the neutral points of sky polarization a few minutes after sunset or before sunrise may be attributed to the existence of well-defined dust layers in the atmosphere. The first of these is the dense dust layer that is often observed from mountain tops to cover the valleys and plains below. It consists of comparatively coarse particles caught up by the turbulent surface wind, and is usually less than a kilometer in thickness. Above this, extending to a height of about 4 kilometers, is the second layer, throughout which some of the finer particles of the first layer have been distributed by means of diurnal convection currents, which are especially strong in summer. The third layer extends from the top of the second to the region of the upper inversion, or to a height of about 11 kilometers, and throughout it some of the finer dust particles of the lower layers are distributed by means of the convective action of cyclones. Above the region of the upper inversion, which is also above the upper limit of convection, what little dust is present must be mostly of meteoric origin, except that volcanic dust is sometimes thrown into these high levels. This was shown to be the case after the great Krakatoa eruption of 1883, by the brilliant twilight phenomena of the two succeeding years.

*The surface dust layer.*—Nearly all human activities are carried on in the lowest dust layer, which is therefore of primary importance. Its density depends upon the relation between the rate of supply and the rapidity with which the particles can be carried away, or distributed throughout the atmosphere. The least dust is found in thinly inhabited regions covered with dense vegetation. In arid regions the surface wind takes up great quantities of dust, which is distributed with considerable rapidity by means of active convection currents. It is in great cities, however, and especially where bituminous coal is burned, that the discharge of soot from numerous chimneys produces the densest dust or smoke layer.

*Quantity of soot in the air of cities.*—Measurements made in Leeds, England, indicate that factories and domestic chimneys annually introduce into the atmosphere of that city 35,000 tons of soot, and into the atmosphere of the United Kingdom 2,420,000 tons. The measurements also show that there is 200 pounds of soot suspended in the air over each square mile of Leeds; that about 11 per cent of this falls in the immediate region where it is generated, and that the remainder is carried to considerable distances before it is deposited (**6**).

An analysis of air collected just outside a second-story window of the University of Pittsburgh, in the residence section of Pittsburgh, Pa., gave for the month of May, 1912, an average of 0.0079 grams of soot per 1,000 cubic feet of air, and for January, 1913, 0.0149 grams. These amounts are equivalent to 200 pounds of soot over each square mile of area in a layer of air about 410 feet and 220 feet thick, respectively.

On foggy days about twice as much soot was found in the air of Pittsburgh as on clear days.

*Deposit of soot in city and country districts.*—By means of soot gages, and from the analysis of rainfall and snowfall, fairly accurate determinations have been made of the rate of deposit of soot at different points on the British Isles and elsewhere. The following are some of the results:

*Rate of deposit of soot in tons per annum per square mile.*

| British Isles: | Tons. |
|---|---|
| Industrial center of Leeds (**7**) | 539 |
| Suburban residence section of Leeds (**7**) | 26 |
| Center of London (**8**) | 426 |
| Sutton, Surrey, just outside the metropolitan area (**8**) | 58 |
| Glasgow (**9**) | 820 |
| Bo'ness (**9**) | 72 |

If the rate of deposit is nearly proportional to the density of the dust layer, as seems probable, it appears that the dust or smoke cloud over the central sections of Leeds, London, and Glasgow, must be from ten to twenty times as dense as in the nearby suburbs.

Measurements of the monthly rate of soot deposit were made at 12 different points in Pittsburgh, Pa., during the year ending with March, 1913. At the point of maximum deposit the annual rate was 1,950 tons per square mile; at the point of minimum deposit it was 595 tons per square mile, while the mean annual rate for all 12 points was 1,031 tons per square mile.

*Limit of visibility.*—Aitken (**10**) found a great variation with wind direction in the limit of visibility in miles of the air at Falkirk, which is so situated that west to north winds come from regions having less than 50 inhabitants per square mile, while winds from all other directions come from regions having a population averaging from 100 to 1,200 per square mile. Table 1 summarizes his results.

TABLE 1.—*Mean limit of visibility in miles of air at Falkirk, for winds from different directions, and with different depressions of the wet-bulb thermometer.*

| Direction of wind. | Depression of wet-bulb thermometer (degrees F.). | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2° | 3° | 4° | 5° | 6° | 7° | 8° |
| West to north | 50 | 100 | 132 | 132 | 198 | 193 | 191 |
| All other directions | 8 | 11 | 14 | 18.5 | 16.4 | 19 | 26 |

Aitken (**11**) has also shown that the product of the number of particles per unit of space by the limit of visibility is a constant $C$ for equal depressions of the wet-bulb thermometer. Some of his results follow in Table 2.

TABLE 2.—*Value of C, the product of the limit of visibility in miles by the number of particles per cubic centimeter.*

| Depression of the wet-bulb thermometer. | C. |
|---|---|
| 2°–4° F. | 77,525 |
| 4°–7° F. | 105,923 |
| 7°–10° F. | 140,628 |

From this table it appears that with a depression of the wet-bulb thermometer of about 5° F., 1,000 particles per cubic centimeter would produce complete obscuration

of large objects like mountains at a distance of 100 miles, while 100,000 would produce complete obscuration at a distance of 1 mile, and 1,000,000 at a distance of one-tenth mile. Tables 1 and 2 are in accord with numerous observations, which indicate that the number of particles per cubic centimeter in large cities may exceed 300,000, even in fine weather, as compared with only a few hundred in the country (**12**). In London in winter the average limit of visibility in the clear part of the day does not exceed one-half mile (**13**), a limit of visibility which corresponds to 200,000 particles per cubic centimeter. In Pittsburgh, Pa., the limit at 7:45 a. m. averages 1.1 miles and at 12:30 p. m., 1.7 miles. This is less than one-tenth the limit at Mount Weather, Va., which has a climate similar to that of Pittsburgh, except that it is free from local smoke.

These figures, however, fail to indicate the relation between the dust or smoke cloud in thinly inhabited districts and in the centers of large cities when for any reason the smoke over the latter instead of being carried away at a reasonably rapid rate, accumulates for a considerable time.

## METEOROLOGICAL EFFECTS OF THE IMPURE AIR OF CITIES.

It is the purpose of this paper to set forth our present knowledge of the effect of the smoke and other impurities in the atmosphere of large cities upon the meteorological conditions. From the preceding paragraphs it is apparent that these effects depend not alone upon the size of the cities and the rate of discharge of impurities into their atmospheres, but also upon the rate at which the vitiated atmosphere is carried away. It follows that the meteorological effects vary with geographical position and with the season of the year; that cities in regions having high average wind velocities are affected less than cities located in regions of light wind; and that the effects are less in summer than in winter, because in summer convection is active and helps to lift the impure air to levels where the stronger air currents will more quickly carry it away. Generally speaking, a city in a valley suffers more than a city in an open plain; and a city in high latitudes suffers more in winter than a city in lower latitudes, on account of the poleward decrease in the heating effect of the sun at this season.

*Effect of smoke upon condensation.*—Aitken (**14**) and others have shown that any considerable condensation of atmospheric moisture takes place only when the saturation temperature has been nearly reached, and then only upon *free surfaces*, such as the surfaces of suspended dust particles. Once condensation has set in, however, it can continue upon the surfaces of the fog particles already formed. In fact, by a process which Aitken calls *differentiation* the smaller fog particles tend to coalesce with the larger particles, until the latter become too heavy to be supported by the atmosphere, and fall to the ground. In this way a fog may rain itself out (**15**).

The analysis of the air of cities shows considerable sulphur dioxide in the residue from burning coal (**16**), and its presence is believed to increase the probability of the formation and maintenance of fog in two ways (**17**): (1) In the presence of sunshine nuclei are formed which have such an affinity for water that condensation sets in at temperatures higher than the saturation temperature; (2) chemical affinity soon arrests the process of differentiation referred to above, so that the fog particles maintain a small size and may be supported in the atmosphere for a long period.

Since there are always sufficient nuclei present in the atmosphere for purposes of condensation, the smoke and other impurities in the atmosphere of cities can not have an appreciable effect upon the amount of precipitation.

*City and country fogs.*—The cooling of the atmosphere to its saturation temperature is usually brought about by the mixture of warm and cold moist air currents, or by nocturnal cooling either by means of radiation outward or by radiation and conduction to the cold ground. These processes are operative in the country as well as in the city, except that the carbon particles in smoke, which are good radiators of heat, will cool below the temperature of the air in which they are suspended, thereby hastening the condensation of moisture upon their surfaces and the formation of fog. Carpenter (**13**) has pointed out that the principal difference between city and country fogs is that the former become mixed with smoke to such an extent that their color is changed from white to brown, or even to black, and their density is so increased that they are almost opaque to sunlight. They attain their greatest density when the surface wind is either very light or else has a direction opposite to that of the wind a short distance above, so that the smoke instead of being blown away is brought back over the city. The accumulation of smoke in fog is also facilitated by reason of the absorption by the soot particles of moisture from the fog, thereby so increasing their weight that instead of rising to their accustomed heights they quickly settle to the lower atmospheric levels.

While there is abundant proof of the increased density of fog in cities as compared with country fogs, the evidence is not conclusive that fogs are more frequent in the city than in the country. However, Brodie (**18**) thought he was able to detect an increase in fog frequency at Brixton, a suburb of London, with increased density of population in that section, and Aitken (**19**) has shown that dense haze or fog frequently forms after sunrise in the impure air of Falkirk when there is no hazing or fogging in the pure air of the surrounding country. There is also some evidence that fog frequency in London has decreased and the hours of sunshine have increased since 1890, perhaps due to a mitigation of the smoke nuisance through improvements in methods of heating and lighting (**18**, **20**). It is generally believed that the same was true of Pittsburgh, Pa., between 1885 and 1895, when the use of natural gas for both manufacturing and domestic purposes was quite general; but this will be referred to again in a later section.

*Effects of impure air of cities upon fog dissipation.*—In the case of chemical union, as where sulphur dioxide unites with water vapor from the air to form sulphurous acid, or where it is first oxydized and then unites with the water vapor to form sulphuric acid, the evaporation of the fog particles is retarded. Smoke from bituminous coal also contains oily or tarry substances (hydrocarbons) which form a coating on the fog particles and retard evaporation.

Furthermore, the increased opacity of black city fogs as compared with white country fogs prevents the heat rays from the sun penetrating to any considerable depth into the former, so that in a great city like London the fog frequently persists throughout the day, while in the suburbs it is dissipated by the midday heat.

*Duration of sunshine in cities.*—It is principally because of this persistence of city fogs that the observed hours of sunshine in large cities are less than in the suburbs. Thus, Russell (**21**) has shown that a station in the heart of London enjoys but seven-tenths as much sunshine as Kew, which is just outside the city, while for the months November to February, when the vertical component of the solar rays is very small, it may have less than one-third as much. Cohen (**22**) has shown that the duration

of sunshine at the center of Leeds is 17 per cent less than at Adel 4 miles distant; and Rubner (**23**) concludes that the duration in Berlin is less than it would be if the smoke cloud were not present.

*Intensity of sunshine in cities.*—Rubner (**23**) further calls attention to the fact that a comparison of the hours of sunshine in cities and their suburbs is not a fair criterion of the actual deficiency of daylight in cities. He cites the fact that while overcast skies are the rule in Berlin in winter, and smoke can not, therefore, greatly diminish the hours of sunshine, measurements with a Weber photometer have shown that on an exceptionally dark day, such as might be attributed to the accumulation of smoke over the city, the light was only one five-hundredth what it was on an ordinary overcast day, and only one three-thousandth to one four-thousandth what it would have been on a day with an entirely clear sky.

Also, Cohen (**22**) has found that the intensity of the light in the center of Leeds is only 40 per cent of its intensity at Adel, a much greater loss than was indicated by the comparison of duration of sunshine at these two places, which is given above.

In Table 3 are summarized observations made at Pittsburgh, Pa., between November, 1912, and May, 1913, inclusive. The observations have been arranged in two groups, the first including days on which the presence of fog or smoke was not recorded, and the second including days on which light or dense fog or smoke was recorded. It will be noted that although the hours of sunshine are practically the same in each group, on days included in the second group fog or smoke has apparently decreased the limit of visibility 20 per cent, and the decomposition of oxalic acid 25 per cent, below the averages for the clear days included in group one. Furthermore, on the smoky or foggy days of the second group, with an average limit of visibility of 0.9 mile the decomposition of oxalic acid was only 76 per cent of what it was under apparently similar atmospheric conditions, except that the limit of visibility was 1.5 miles. In other words, a decrease of 40 per cent in the limit of visibility was accompanied by a decrease of 24 per cent in the decomposition of oxalic acid. It is presumed that the decomposition of oxalic acid is proportional to the intensity of daylight.

A comparison between observations made in Pittsburgh and in Sewickley, a small suburban town about 12 miles northwest of Pittsburgh, shows that the oxalic acid decomposition under the smoke cloud of the city is only 60 per cent of what it is in the country.

In both cases the glass vial containing the acid has been exposed outside the window in a small box with the open side facing accurately east.

TABLE 3.—*Relation between sky conditions and the decomposition of oxalic acid when exposed to daylight, at Pittsburgh, Pa.*

| Hours of sunshine. | Limit of visibility. | Oxalic acid decomposition. |
|---|---|---|
| GROUP 1.—DAYS WITHOUT SMOKE OR FOG. | | |
| | *Miles.* | *Per cent.* |
| 4.1 | 1.2 | 13.74 |
| 4.0 | 1.8 | 14.43 |
| GROUP 2.—DAYS WITH SMOKE OR FOG. | | |
| 4.1 | 0.9 | 9.06 |
| 4.2 | 1.5 | 11.99 |

*Quality of daylight in cities.*—Pyrheliometric observations (**24**) made at different places indicate a very considerable decrease in the intensity of direct insolation after violent volcanic eruptions, due without doubt to the scattering of the solar rays in passing through the dust or smoke that has been thrown to great heights by the eruption. Spectrobolometric measurements made under the direction of the Astrophysical Observatory of the Smithsonian Institution (**25**) show that light of short wave lengths suffers a greater depletion than light of long wave lengths in passing through a clear atmosphere, and that the further depletion in passing through a hazy atmosphere is relatively greater for short wave lengths than for long wave lengths. Furthermore, bolometric measurements made on Mount Wilson (**26**) in 1905 and 1906 indicate that the ratio of blue to red in diffuse skylight is six times the ratio of blue to red in direct sunlight.

The above accurate instrumental measurements confirm what we are able to observe with the unaided eye, viz, that both the direct and the diffuse solar radiation which filters through the smoke cloud hanging over cities is relatively poor in the blue light, or light of short wave lengths.

Although bolometric measurements of solar spectrum energies at the bottom of a smoke cloud are not available, it is safe to say that when the sun is near the horizon the smoke cloud over great cities almost completely extinguishes the blue light rays.

*Effect of the smoke cloud on city temperatures.*—The presence of dust or smoke particles in the atmosphere, by decreasing its transmissibility for light and heat waves as has just been shown, affects atmosphere temperatures in three ways:

(1) There is an increased scattering of the incoming heat rays, which are also partly absorbed by the dust or smoke particles, thereby raising the temperature of the atmosphere in which the latter are suspended.

(2) The rays reaching the surface of the earth are much weaker than they would have been if they had not been scattered and absorbed. In fact, in the case of dense fog or smoke almost no heat penetrates to the surface of the earth, but the upper boundary of the fog or smoke cloud becomes in effect the absorbing surface. In such cases the temperature above the cloud becomes much higher than the temperature in the cloud. Carpenter (**27**) mentions an instance in London where the surface temperature was 44° F., while on the roof, nearly vertically above and 59 feet higher, the temperature was 51.5°, or 7.5° higher, although generally the temperature was found to decrease with altitude at the rate of 0.52° F. per 100 feet. On this particular occasion the surface temperature rose from 36.5° to 44° between 9 a. m. and 3 p. m., or a range of temperature of 7.5°, while on the roof above it rose from 35° to 51.5°, or a range of 16.5°. At Kew, on the same date, the range was from 32.5° to 54°, or 21.5° F.

(3) There is less radiation from the ground and outward from the lower part of the atmosphere and from particles suspended in it. This tends to give higher minimum temperatures in cities than in their suburbs. In fact, this principle is extensively employed in protecting small fruits and garden truck from injury by frosts. A smoke cover is formed, which acts as a blanket to prevent the loss of surface heat by radiation.

On the whole, then, the effect of a smoke cloud is to raise the minimum temperatures, decrease the diurnal range of temperature, and, in case of a very dense cloud, to lower the maximum temperatures. It is possible to conceive of a smoke cloud of such depth and density that the maximum temperatures will be raised.

Hammon and Duenckel (**28**) found that the minimum temperatures at Forest Park, a suburb of St. Louis, Mo., were sometimes 20° F. lower than at the Weather Bureau office in the heart of the city. The differences were greatest in September when the air at the Park was clear, while light winds allowed the smoke to accumulate over the city in a dense cloud of great thickness. The differences were least in the cloudiest months—December and March. The thermometers at the Weather Bureau office were 110 feet above ground, and at Forest Park 10 feet.

Smith (**29**) has found a similar, though less marked, difference between the temperatures recorded at the Weather Bureau office, Columbus, Ohio, and the Ohio State University, located about 3 miles north of the center of the city. At the Weather Bureau office the thermometers have been exposed in a shelter on the roofs of several different office buildings, and at present are 170 feet above the ground. At the University the shelter is 6 feet above the sod. His conclusions are based on a summary of the observations for the 29 years, 1883 to 1911, inclusive.

The conditions at Pittsburgh, Pa., are of especial interest. According to the statement of Mr. Henry Pennywitt, in charge of the Weather Bureau office at Pittsburgh,—

> Previous to 1885, when soft coal was almost exclusively used for fuel for both domestic and manufacturing purposes, the air was ordinarily filled with smoke and soot, and many dark days were the result. About 1885 natural gas became very plentiful and cheap, largely supplanting soft coal as a fuel, and the air became comparatively free from smoke. The price of gas was increased about 1895, and the use of soft coal was again resorted to, with the result that the air was again filled with smoke. In the years 1905–1907 many days with dense smoke were recorded; but the panic of 1907–8 resulted in a diminished use of coal in manufactories, and there has been an improvement in domestic furnaces and methods of stoking, so that the volume of smoke has again been greatly diminished. However, the air in the vicinity of Pittsburgh is never free from smoke, except after a rain or snow storm, and with high westerly winds.

In Table 4 the average maximum and minimum temperatures and the range of temperature, in Pittsburgh, have been arranged in four groups: (1) 1875–1884, corresponding to a period of dense smoke, according to the above statement; (2) 1885–1894, to a period of comparatively light smoke; (3) 1895–June, 1904, to a period of dense smoke; and (4) July, 1904–Dec., 1911, to a period of decreasing smokiness.

TABLE 4.—*Average annual maximum and minimum temperature and range of temperature at Pittsburgh, Pa.*

| Period. | 1875–1884 | 1885–1894 | 1895–June, 1904 | July, 1904–1911 |
|---|---|---|---|---|
| | °F. | °F. | °F. | °F. |
| Maximum | 62.7 | 61.9 | 61.9 | 61.0 |
| Minimum | 43.4 | 44.0 | 44.6 | 43.6 |
| Range | 19.3 | 17.9 | 17.3 | 17.5 |

The elevation of the thermometers above ground was about 88 feet during the first period, about 120 feet during the second and third periods, and 336 feet during most of the fourth period. The increase in elevation at the end of the first period appears to have decreased the diurnal range of temperature about 1.4° F., while the further increase in elevation at the end of the third period appears to have decreased both maximum and minimum temperatures by about 1° F. During the smoky third period the minimum temperatures averaged about 0.6° F. higher than during the comparatively clear second period.



While in each of these cases the temperature shifts are in the direction in which we would expect them to occur as the result of the local conditions above described, we can not state with certainty that they are entirely the result of changes in the elevation of the instruments, or of variations in the smokiness of the atmosphere. It may be that changes in the character of the instrument shelter, as from a window to a roof shelter, and in the character of surrounding buildings, may also have exerted an influence, the extent of which it is impossible to estimate.

In Table 5 are summarized comparisons between the minimum temperature and the range of temperature at the Weather Bureau office in St. Louis and the suburban station in Forest Park; at the Weather Bureau office in Columbus, Ohio, and the suburban station at the State University; and at the Weather Bureau offices in Pittsburgh, Pa., Philadelphia, Pa., Williamsport, Pa., and Harrisburg, Pa., and at stations surrounding these centers, but in some cases several miles distant, and at a considerably different elevation above sea level.

The comparisons for St. Louis include observations for 1 year, those for Columbus 29 years, and those for the four remaining stations the 10 years 1902–1911, inclusive.

TABLE 5.—*Excess of minimum temperatures, and deficiency of range of temperature in cities as compared with the surrounding country.*

| Month. | St. Louis. | | Columbus. | | Pittsburgh. | | Philadelphia. | | Williamsport. | | Harrisburg. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min. | Range. | Min. | Range. | Min. | Range. | Min. | ange. | Min. | Range. | Min. | Range. |
| | °F. | °F. | °F. | °F. | °F. | °F. | °F. | °F. | °F. | °F. | °F. | °F. |
| January | 2.5 | 1.6 | 2.1 | 2.0 | 3.0 | 3.0 | 3.6 | 2.7 | 3.0 | 2.8 | 2.6 | 3.7 |
| February | 2.9 | 2.8 | 1.2 | 1.3 | 2.6 | 2.5 | 3.8 | 3.2 | 2.6 | 2.3 | 2.6 | 4.3 |
| March | 1.6 | 0.5 | 2.7 | 2.3 | 3.7 | 3.8 | 4.0 | 4.2 | 2.8 | 2.9 | 4.2 | 4.7 |
| April | 4.4 | 3.7 | 3.2 | 3.6 | 3.8 | 5.6 | 4.7 | 4.3 | 3.0 | 2.9 | 3.6 | 5.9 |
| May | 5.5 | 4.8 | 3.2 | 3.3 | 5.2 | 6.9 | 3.9 | 4.1 | 3.2 | 3.3 | 4.2 | 6.9 |
| June | 3.7 | 2.3 | 2.8 | 2.9 | 4.5 | 5.8 | 3.7 | 3.0 | 2.8 | 3.2 | 3.3 | 5.9 |
| July | 5.5 | 4.0 | 3.2 | 3.4 | 4.9 | 6.2 | 4.5 | 4.4 | 3.2 | 4.2 | 4.3 | 6.4 |
| August | 4.8 | 4.2 | 3.4 | 4.1 | 5.0 | 6.6 | 4.4 | 4.4 | 2.2 | 3.8 | 3.7 | 6.1 |
| September | 9.0 | 9.0 | 3.5 | 4.3 | 4.4 | 7.6 | 4.7 | 4.2 | 2.8 | 3.4 | 3.5 | 5.3 |
| October | 5.8 | 5.9 | 3.8 | 4.5 | 4.4 | 5.9 | 5.6 | 5.7 | 2.7 | 2.8 | 3.8 | 5.6 |
| November | 2.2 | 2.2 | 2.9 | 3.2 | 4.5 | 4.6 | 5.1 | 4.5 | 2.4 | 3.0 | 3.7 | 5.0 |
| December | 1.8 | 1.5 | 1.9 | 2.0 | 3.0 | 3.1 | 5.0 | 3.2 | 2.7 | 2.7 | 3.1 | 4.3 |
| Year | 4.1 | 3.5 | 2.8 | 3.1 | 4.1 | 5.1 | 4.4 | 4.0 | 2.8 | 3.1 | 3.6 | 5.4 |

At the outlying stations, and also at Williamsport, the thermometers have been exposed in a shelter but a few feet above the ground. At Pittsburgh they are now 353 feet above the ground, at Philadelphia 123 feet, and at Harrisburg 94 feet; but the elevation at Pittsburgh has been changed during the period of comparison, as has already been shown.

From Table 5, it is seen that the minimum temperature at the six stations under consideration averages about 3.6° F. higher, and the range of temperature 4° less than the corresponding data for surrounding stations. The maximum temperature must therefore average about 0.4° lower. The differences have a maximum in the warm months of the year.

The maximum temperatures in the city are generally low during the warm months by approximately the amount that may be attributed to the greater elevation of the thermometers above the ground, or by about 0.5° F. per 100 feet. Only a part of the minimum temperature excess can be attributed to this cause, the rest being undoubtedly due to some city influence.

Bolton (**30**) has computed that the total heat emitted from all sources in the city of New York, but principally from the combustion of fuel in average winter temper-

ature of 40° F., would add 2° F. to the temperature over an area of 326 square miles to a height of 1 mile. This could only be true when there was no movement of the atmosphere, a condition that only occasionally prevails; and the effects of the heating would be more marked in winter than in summer. Evidently some other influence also has a part in modifying the minimum temperatures of cities.

Table 6 shows that in cities the minimum temperature excess is more pronounced on days when dense smoke prevails. We are therefore justified in attributing a part of the excess in the monthly mean minimum temperature of cities to the general smokiness of their atmospheres.

TABLE 6.—*Departures of the maximum and minimum temperature and the range of temperature in cities, when smoke or fog was dense, from the corresponding averages at surrounding stations.*

| Station. | Maximum. | Minimum. | Range. |
|---|---|---|---|
| | ° F. | ° F. | ° F. |
| Pittsburgh | −0.9 | +6.5 | −7.4 |
| Philadelphia | −0.4 | +6.9 | −7.3 |

Table 6 also shows that the maximum temperatures are not affected to the same extent as the minimum temperatures. This is because the smoke is densest during the morning hours, the convection of midday helping to carry it away. At the same time the more thorough mixture of city and country air tends to equalize temperatures over the two regions, and it may also be that the absorption of heat by the smoke particles tends to increase the maximum temperatures.

Williamsport, Pa., is a small city in which the effects of city heating must be slight; and since the thermometers have had exposures similar to those at surrounding stations, namely, in a shelter a few feet above the ground, the only known reason why the minimum temperature should show the excess revealed by Table 5 is the influence of the smoke cloud, which is quite dense at times owing to the extensive use of bituminous coal for manufacturing purposes.

Between December, 1912, and May, 1913, inclusive, temperature readings were obtained from thermometers exposed a few feet above the sod in a park in Allegheny, Pa., just across the river from the Weather Bureau office in Pittsburgh, and from thermometers similarly exposed at Sewickley, Pa. The results, which are summarized in Table 7 show rather small differences between the readings at Allegheny and the Weather Bureau office in Pittsburgh, but differences between the readings at Allegheny and Sewickley of about the magnitude that would be expected from the comparisons summarized in Table 5.

Other conditions being equal, the diurnal range of temperature should be proportional to the amount of heat received during the day; but, as already stated, it seems probable that in the cases under consideration the diminished diurnal range of temperature is due principally to retardation of nocturnal cooling by the smoke cloud over the cities.

TABLE 7.—*Differences between temperatures in Pittsburgh and its suburbs.*

| Stations. | Maximum. | Minimum. | Range. |
|---|---|---|---|
| | ° F. | ° F. | ° F |
| Allegheny—Weather Bureau, Pittsburgh | +0.8 | −0.3 | +1.1 |
| Allegheny—Sewickley | −0.1 | +3.3 | −3.4 |
| Sewickley—Weather Bureau, Pittsburgh | +0.9 | −3.6 | +4.5 |

I am indebted to Mr. George S. Bliss, section director, United States Weather Bureau, in charge of the Pennsylvania section, for the data for Philadelphia, Williamsport, and Harrisburg, and for information relative to conditions prevailing at these stations.

## SUMMARY.

1. City fogs are more persistent than country fogs, principally because of their increased density on account of the smoke that accumulates in them.

2. In consequence of the above there are fewer hours of sunshine in cities than in the country.

3. In the clear part of the day in winter in London the average limit of visibility does not exceed one-half mile. In Pittsburgh it averages about 1½ miles. This latter is less than one-tenth the average limit of visibility in the open country about Pittsburgh.

4. The chemical action of light in smoky cities has been found to be 40 per cent less than in the open country, and over 20 per cent less on smoky days than on comparatively clear days.

5. Minimum temperatures are markedly higher in cities than in the country, partly on account of city heating, but principally because the smoke acts as a blanket to prevent the escape of heat at night.

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## NEW DAILY WEATHER MAP.

The daily weather map of the Northern Hemisphere now being published by the United States Weather Bureau, is likely to become invaluable to all who are actively interested in the study of the free atmosphere, as distinguished from the study of the air near the earth's surface that directly belongs to agriculture and climatology.

The edition presents both the second edition of the regular 8 a. m. map of the United States and, on the reverse, the daily map of the Northern Hemisphere. It is limited to a few hundred copies and is sent to libraries, meteorological offices, and a few special meteorological students. Copies are dispatched either daily (folded), or in weekly rolls, or in monthly rolls, by mail or through the International Exchange Service of the Smithsonian Institution, according as requested by the respective recipients. Copies are also to be purchased through the United States superintendent of public documents at $3 per year or 30 cents per month. The following letter accompanied the first issue:

WEATHER MAP OF THE NORTHERN HEMISPHERE.

On January 1, 1914, the United States Weather Bureau began the publication at Washington of a weather map of the Northern Hemisphere, a copy of which accompanies this announcement. Hereafter this map will be printed on the reverse side of the morning weather map of the United States. A similar manuscript map of the Northern Hemisphere has been prepared daily for several past years in the Weather Bureau, and has proved of great value to the forecasters in predicting general changes of the weather, and especially in extending the periods for which such forecasts can be successfully made. Although the number of reports available for the construction of the map is limited at present, and the times of obeservation are not all strictly simultaneous, nevertheless the essential features of the atmospheric circulation over the Northern Hemisphere are fairly well depicted.

In beginning this important publication it seemed advisable not to retain the arbitrary and irrational units ordinarily employed for measuring pressure and temperature of the atmosphere, but to adopt the more scientific and rational units of the C. G. S. system. Accordingly, the reported pressures are all expressed in dynamic units in which a pressure of 750.06 mm. of mercury corresponds to a force of 1,000,000 dynes. Following the suggestion of Bjerknes, this absolute unit of pressure is called 1 bar=1,000 millibars. The reported temperatures have all been reduced to the absolute scale (Centigrade) on which the temperature of melting ice is 273°.

Mathematical and dynamic studies of the motions of the atmosphere are possible only when the data are given in rational units of the kind described. It is hoped the publication of this map of the Northern Hemisphere will facilitate and promote the serious scientific study of the great and complex problems of the general circulation of the atmosphere.

C. F. MARVIN, *Chief of Bureau.*

This new daily weather map of the Northern Hemisphere has received general commendation both in Europe and America The world's progress in telegraphy has thus made possible this modification of the ideas carried out by Gen. A. J. Myer in 1872 in his "International Bulletin of Simultaneous Meteorological Observations." That bulletin was dropped in 1889 by the Chief Signal Officer, presumably because of expense. It was revived in different form as a part of the marine meteorological work of this bureau in 1894; its map has been maintained in manuscript as a part of the forecast work since 1895. Prof. C. F. Marvin has returned to the original polar projection (Postel-Werner) and the map is now published daily by lithography as nearly as possible in agreement with the ideas of all prominent students of the free atmosphere. We quote a few acknowledgments:

**Bjerknes,** Leipzig, January 29, 1914:

I have been pleased to see the publication of your daily weather map for the Northern Hemisphere. The introduction of the C. G. S. units is a very great progress indeed.

**Gold,** London:

I must write to congratulate you on the energetic way in which you have tackled the question of units and on the beautiful Northern Hemisphere charts in millibars and absolute degrees, of which you have sent me a copy. * * * You will probably see that absolute units have also been used from January 1 for the daily charts which are issued with the Weekly Weather Report.

**Hergesell,** Strassburg:

I have received with much interest the first weather map of the Northern Hemisphere. * * * Precisely in the work of the International Commission for Scientific Aeronautics, this map will be a great help and a great advantage. I believe that all problems of general meteorology, which embrace, not local studies but the great problems of the general circulation, will receive a great encouragement from this publication.

**Wilfred M. Wilson,** Ithaca, N. Y., professor of meteorology:

I beg to offer my congratulations on this important advance which, I feel sure, will tend toward the realization of the hope expressed in the last paragraph of your memorandum, as to the "serious scientific study of the great and complex problems of the general circulation of the atmosphere."

**Charles Stewart,** Spokane, Wash., local forecaster:

The map of the Northern Hemisphere supplies a long-felt want. It is of great value for forecast studies and its daily publication will be gladly welcomed.

**Dr. W. Köppen,** Hamburg, January 22, 1914:

With great interest and delight I have to-day received the new daily weather map for January 1, 1914, with the weather map of the Northern Hemisphere. The transition to the millibars was a delightful surprise. In reference to the isotherms I would urge that they be drawn for the absolute temperatures 268°, 273°, 278°, 283°, etc., instead of for 270°, 275°, etc.

It is also desirable to accentuate the isotherm of 273° by a thicker line in order to bring the frost region of winter into prominence.

**Wm. Marriott,** secretary, Royal Meteorological Society, London, January 23, 1914:

The publication of such a map is a great advance in meteorology and will help us to understand better many of the problems of the general circulation of the atmosphere.

**R. Siedek,** Central Hydrographic Office, Vienna, January 29, 1914:

The K. k. hydrographische Zentral Bureau most heartily welcomes the new daily weather map of the Northern Hemisphere, published by the United States Weather Bureau.

**W. H. Hammon,** formerly district forecaster at San Francisco:

I have your new map of the Northern Hemisphere on the reverse side of the morning weather map. I think this is the most valuable scientific step taken by the Weather Bureau in many years, and I believe very valuable results will ensue. * * * When I was in California I made a series of daily weather maps of the Pacific Ocean from the hydrographic reports and drew the best lines I could. I believe this information was extremely valuable in perfecting the system of forecasts which we followed in California. This series of maps was among the serious losses that resulted from the San Francisco fire [April, 1906].

**C. Hart Merriam,** executive of the "Harriman Trust Fund":

Your new departure in printing the Northern Hemisphere weather map on the back of the United States weather map is a great advance, and I congratulate you on having brought this about.

**Prof. Ellsworth Huntington,** Yale University:

The idea of giving a general map of the entire Northern Hemisphere is extremely useful. * * * For the nonscientific man who is interested in the weather they are sure to prove educational. * * *

**Prof. Dr. Felix Exner,** K. k. Universität Innsbruck. March 4, 1914:

* * * A copy of the International Map for the Northern Hemisphere for January 1, 1914, has come to my Institute, and I admired very much this great progress in weather maps.

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## THE WEATHER MAP ON THE POLAR PROJECTION.

One can not examine a series of the new daily weather maps of the Northern Hemisphere without realizing that this publication is destined to throw great light on the motions of our atmosphere and on the periodic as well as the quasi-periodic and the irregular changes of our weather and storms. Especially does it renew that stimulus to the study of the mechanics of the earth's atmosphere, which was first given by the memoirs of William Ferrel. His study of 1858–1860, which he began in 1856 as a popular essay, was reprinted as Professional Paper of the U. S. Signal Service, No. 8 Washington, 1882, with notes by Prof. Frank Waldo. This, together with his many other studies, will always command our admiration, no matter what advances may hereafter be made in the mathematical treatment of atmospheric motions. Ferrel taught us that the diurnal rotation of the earth on its axis, the attraction of gravitation, and the distribution of temperature near the earth's surface, are the three fundamental factors that must be considered. Subsequently he discussed the differences of friction over land and water; the thermodynamics of ascending and descending masses of air; the influence of the distribution of moisture; finally, toward the close of his life, he began the consideration of the influences of radiation and absorption.

So far as we know no one has as yet dared to begin the discussion of the motions of the atmosphere under the combined influences of all these seven factors and yet these must be gathered into one set of systematic equations or graphic charts, if we would fully understand the phenomena shown by the daily weather map. In fact, an eighth factor must be added, viz, the influence of high plateaus and mountain ranges as superadded to the influences of the lower continental surfaces. Eventually we may consider the ninth factor, viz, the influence of viscosity. When we consider the simple hypothetic atmosphere treated of at first by Ferrel, we perceive that the denser portions of the air are thrown toward the Equator by the diurnal centrifugal force, but that there must be a return current toward the pole of the warmer lighter air, thus giving rise to currents and whirls which become either cyclonic or anticyclonic since the attraction of gravitation holds the atmosphere near the surface of a rotating spheroid. These whirls give rise to the areas of high pressure and low pressure of which we usually see from three to a dozen dotting the map of the Northern Hemisphere. Usually we may consider the air flowing toward the pole as warmer, lighter, and rising, while that flowing toward the Equator is colder, drier and descending. Innumerable obstacles start smaller whirls that are scarcely noticed among these general features.

Our polar map of the Northern Hemisphere shows at a glance that our storms and our blizzards, our hot areas and our hurricanes, are due to the interchanges of air between the Torrid Zone and the Arctic region. A dozen such centers of action are sufficient to enable the atmospheres of northern and southern latitudes to maintain steady interchanges of position without any violent actions, just as earthquakes and minor fractures produce minor earthquakes that save our globe from any extreme cataclysms. For instance, some portion of the atmosphere over the North Polar region, being cooled by atmospheric and terrestrial radiations as also by the expansion of moist air against atmospheric pressure, deposits much of its moisture as rain or snow, becomes relatively denser, and is then pushed southward. There is a resulting region of low pressure about which the winds circulate. This area is sometimes nearly circular and at other times much elongated. The elongated trough may extend from Norway to northern Siberia, or from Newfoundland to Norway, or from the north of Alaska to Labrador. In fact, this trough must oscillate all over the Arctic region from day to day and month to month, in a quasi-periodic fashion depending on the sum total of the moments of inertia of the whole atmosphere relative to our polar axis. Our polar and equatorial winds circulate around this trough, and our large storm centers circulate with it around the pole. Hence these storm centers may come upon the United States most unexpectedly from the northwest or southwest, or from the south or southeast. The map of the United States between latitudes 30° and 50° only, gives us no indication of the causes of these irregularities, whereas the map of our whole hemisphere shows at once that they represent whirls in an atmosphere that thereby attempts to maintain a dynamic equilibrium in each hemisphere. It is the excess of continental resistances obtaining in the northern hemisphere over the southern that allows of the interchange of circulations between it and the southern one. It would be utterly wrong to study our moving atmosphere as a problem in statics. A slight disturbance of static equilibrium produces a complete upset of the dynamic equilibrium and from that moment its readjustment becomes the dominating feature of the atmosphere.

Static equilibrium has never existed throughout the atmosphere of our globe. It is only approximated over comparatively small regions, and for short intervals of time. As to dynamic equilibrium Helmholtz has shown

that in an ideal frictionless liquid many whirls or vortices may exist side by side but separated by surfaces of discontinuity and without influencing each other's internal motions; but even this case does not refer to the existing earth's atmosphere unless we ignore viscosity and surface friction. Each one of our great vortices has an influence on whatever is near by. An area of low pressure with its center over Iceland, with southerly winds from Ireland northward over Spitzbergen and Nova Zembla, is accompanied by an overflow of air on to an area of high pressure over Siberia; there the air slowly cools and descends from the upper regions of the atmosphere down upon the cold Arctic region, thence it is drawn into the western half of a low-pressure area over Alaska and the Pacific coast and western Canada. Eventually this cool, dry denser air reaches Texas, the Gulf of Mexico, the Tropics as an underflow; after rising as warm moist air above the trade winds, it begins its next slow fall along an inclined plane north and east toward northern Europe. Every area of low pressure and high pressure includes these regions of rising lighter and descending denser air. If there are no resistances between our atmosphere and the exterior space, then its own internal mechanism must be in dynamic equilibrium.

The present problem in meteorology is to trace on our circumpolar map the lines of flow, or so-called atmospheric stream lines, day by day. From them we may argue backward to the lines of pressure or isodynamics, or lines of force; or, vice versa, we may theoretically determine the lines of force and thence derive the lines of flow. The latter study may be contemplated by Prof. Roever in a paper "On the theory of a mechanism for illustrating certain systems of lines of force" (to appear in Bulletin, Mount Weather Observatory, vol. 6, pt. 5). As the analytics is very complex, he treats a simpler problem by mechanical methods. Another attack upon this problem by a method appropriate for the laboratory is suggested in an article on "Comprehensive maps and models of the globe" (Monthly Weather Review, Washington, December, 1907, p. 559–564, with charts.) When we express the dynamic equations in all their complexity and attempt to solve them by analytical methods, we shall undoubtedly have recourse to graphic methods for the integration of complex functions, as illustrated in a paper by Dr. S. D. Killam, of the University of Alberta, to appear in an early number of this Review.

On the other hand, when sufficient data for any date are available for an approximate presentation of the conditions then existing in the upper air, the student will be able to attain precise results for that date by following out the methods of study expounded by Bjerknes in his "Dynamic Meteorology," or in the preliminary studies by his pupil, J. W. Sandström, "On the construction of isobaric charts for high levels in the earth's atmosphere and their dynamic significance." This latter memoir was written by Sandström in 1901, in response to a request from the Editor, in order to elucidate a proper graphic method of utilizing the important series of kite flights at 17 stations carried out by the United States Weather Bureau in the summer and autumn of 1898.

In 1871, which was the first year of the regular forecast work of the Weather Bureau, the present writer was deeply impressed with the conviction that the atmosphere must be studied as a unit and that neither a continent nor an ocean could properly be considered by itself alone. In order to lay the basis for the proper study of the storms of the Northern Hemisphere, and being deeply impressed with the importance of this view, Gen. Albert J. Myer, as the founder of the Signal Service, visited or corresponded with all the important meteorological and hydrographic offices throughout the world. He then attended the International Meteorological Congress at Vienna, September, 1873 (see Weather Bureau Bull. 11, Washington, 1897, p. 257), and asked it to endorse the desirability of his proposed daily simultaneous observations and charts.

The "Bulletin of International Simultaneous Observations" was undoubtedly the finest piece of international coöperation that the world has ever seen; it was published daily for about 10 years, and in a modified form until December, 1889. Of course, the fact that all data from lands and seas were printed in full, exactly one year after date, in tabular form, in both English and metric systems, with accompanying daily charts of the Northern Hemisphere, added enormously to the expense as compared with the present method devised by Professor Marvin, whose chart is made possible by the free use of the modern systems of telegraph, cable, and wireless, so that it can accompany the regular issue of the daily Weather Bureau map on a comparatively large scale.

Not only does the present map of the Northern Hemisphere show approximately the existing relation between pressures and temperatures in dynamic units over the earth's surface, but we also, by comparing the charts day after day, quickly perceive the origin of the geographic relations that had already been empirically deduced, e. g., the seesaw of pressure and temperature between distant regions; the reasons for the existence of the polar low pressure shown by Köppen's methods of reducing upward (see Monthly Weather Review, Washington, 1896, p. 419); the probable success of future attempts at world-wide, long-distance predictions, such as that made for northern India, based on the high-level records of November 17–27 (See Monthly Weather Review, 1896, p. 420.)

We perceive why the axes of the polar troughs must move irregularly about the pole so that the average for long periods of time becomes a nearly stationary polar depression. We perceive that the glacial phenomena and other climatic peculiarities must go through slow stages of change, but without any systematic periodicity. We see how insignificant is the influence of the Japan Current and Gulf Stream on continental climates. The temporary historic changes in climates; the occasional occurrence of a deluge or a great drought; the frequent recurrence of warm or cold, wet or dry years; are all seen to be due to rare combinations of forces, motions, or conditions that can only recur after many ages. We even perceive that while geologic ages have brought about very slow changes in the distribution of altitudes, mountains, continents, and oceans, there must have been equally slow changes in our plants and birds, enabling the latter to learn to travel great distances annually in search of desirable foods and habitats, while our atmosphere itself has continued to maintain its annual interchange between equatorial and polar regions.

The contemplation of this persistent circulation in our atmosphere and the changes that have occurred in the orography of the globe, must impress one profoundly with the conviction that for untold ages the earth has been fit for the home of man and of every form of life. If the study of our new map of the Northern Hemisphere forces us as meteorologists to give our prime attention to the fundamental mechanics of the atmosphere, we shall have reason to congratulate ourselves on the conditions that have made its publication possible. May we not adopt the enthusiastic words of the immortal Kepler,

in his "Harmonies of the World," "The die is cast! The book is written! It can well afford to wait a century for a reader, since God has waited 6,000 years for the astronomer."—[C. A.]

## WINSLOW UPTON, 1853–1914.

We regret to note the death of Prof. Winslow Upton, on January 8, in the sixty-first year of his age. He will be remembered by many in the Weather Bureau as an active member of the "Study Room" established by Gen. W. B. Hazen, as Chief Signal Officer, in January, 1881. Although Professor Upton was with us only a few years, yet his activity and his extensive knowledge contributed greatly to the usefulness of this official effort to introduce a higher scientific standard into the work of the Weather Bureau. When President Garfield appointed General Hazen the Chief Signal Officer, intrusted with the conduct of the Weather Bureau, the latter was urged by the lamented President "to give the right hand of fellowship to science as such." It was in obedience to this advice that Winslow Upton was drawn from the Naval Observatory into the Weather Bureau of the Signal Office. In 1884 he was appointed professor of astronomy at Brown University, and within a few years supervised the construction of the Ladd Observatory, where regular meteorological observations have been kept up. Upton was one of the organizers of the New England Meteorological Society in June, 1884, and most active early contributors to its bulletins. This society was supported by such eminent men as W. H. Niles, W. M. Davis, D. Fitzgerald, E. B. Weston, W. Upton, A. Lawrence Rotch, M. W. Harrington. It also exerted a decided influence in favor of the appointment of M. W. Harrington on July 1, 1891, as the first Chief of the Weather Bureau under its new scientific organization. A similar "Ohio State Meteorological Bureau" had been established April 17, 1882, by action of the State Legislature and attained great usefulness under T. C. Mendenhall as the active president of the board of directors, he being also at that time professor of physics in the State University at Columbus. In those days, under the wise administration of Gen. W. B. Hazen, great interest was manifested in the organization of independent State weather services throughout the country. (See Annual Report of Chief Signal Officer for 1881, pp. 71–72.) But this was soon transmuted into the establishment of State services under the conduct of Weather Bureau officials, and the support of the Chief Signal Officer. The stimulus given to intellectual activity by the establishment of independent services may possibly break up the quiet and homogeneity of routine climatological work, but it does far more good than harm by stimulating every man to see if he can possibly improve on what has gone before. As these independent State services have now almost entirely disappeared and are almost forgotten because merged with the general Weather Bureau official system, we have thought it important to dwell upon Professor Upton's activity in this early organization and his thorough sympathy with the desire to stimulate independent thought. The degree of Ph. D. in the German and in many American universities must be accompanied by a thesis in which the candidate illustrates his own adaptability or power of original investigation, and Prof. Upton's life gave many such evidences of his own gifts, both in astronomy and meteorology.—[C. A.]

## THE DRIFT OF A TRAIN OF A BRIGHT METEOR.

Almost the only information that we can obtain with regard to the motions of the highest portions of our atmosphere comes from observing and studying the slow drift of the delicate train of light or luminous dust left behind when a bright meteor passes through the upper air.

The following note from Mr. Frise, of Sheridan, Wyo., shows that the meteor train observed by him January 12 drifted rapidly eastward as its particles settled toward the earth. We should have gained much exact knowledge from this meteor if only observers at other stations could have made records of its appearances as seen by them, but certainly we are authorized to conclude that a strong easterly wind, or possibly from the west by south, must have been prevailing in the upper atmosphere at that time. Prof. C. C. Trowbridge, of Columbia University, calls attention to the value of the information that may be obtained from the phenomena of meteor trains.

Photographic apparatus appropriate to the prompt record of such meteor phenomena has long since been designed and will, it is hoped, become available to observers during the coming year.—[C. A.]

LOCAL OFFICE, U. S. WEATHER BUREAU,
*Sheridan, Wyo., Jan. 14, 1914.*

As the regular evening observation was being made on the 12th instant my attention was attracted to an optical phenomenon in the west unlike any before observed. No instrument was available for determining the true position, but the desire to locate as accurately as might be done by eye observation came to me at once, so that with the care which that desire prompted, the estimated position is not much in error. The altitude was about 12° to 15° and azimuth about 75°. It was first observed at 5:45 p. m. local time (105th Mer.), and at 6:05 p. m. it was very faint and disappeared at 6:07 p. m. It was apparently a chain of stars about 6° to 10° in length in

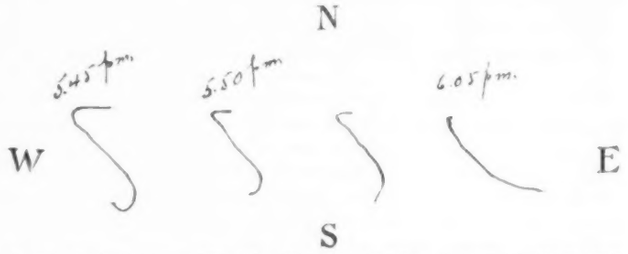


FIG. 1.—Train of meteor at Sheridan, Wyo., Jan. 12, 1914. Appearance of train at 5:45 p. m., 5:50 p. m., and 6:05 p. m.

the form of an imperfect letter *S*, closely resembling the figures accompanying which were drawn as the observation was made. It [the trail] was nearly upright when first seen, but as it shortened and straightened it resembled a shepherd's crook or staff by the time it had become so faint as to be scarcely discernable.

Its light was identical with that of a bright star, no color appearing at any time. With the diminishing brightness of the light it seemed to rise slightly and the lower portion at times seemed to draw up so as to shorten the figure. Whether this was due to actual motion or to an unsteady medium through which its light came was not apparent. But that the shape of the figure was

different at the close of its visibility from that seen at 5:45 is known without any doubt. On first noticing this phenomenon the impression was of a chain of stars, each separated from the next by a short space and all mingling their light into a line of white light of the shape before mentioned, but as a few minutes elapsed this appearance was not so noticeable. From a nearly upright position when first seen it had assumed one at an angle of about 45°, with the upper extremity to the left. There was no head, such as is usually seen in a comet, and one portion seemed as bright as another. Only flecks of cloud were in the sky at that time so that no obstruction interfered at any time. The width of the line of light was about that of a bright star, but in brilliancy it outshone any star in that portion of the sky. Inquiry does not as yet add the testimony of others who might have seen the phenomenon had they been out away from trees and buildings, and while it did not resemble any comet that the observer has ever seen, it has seemed impossible to ascribe any other explanation. Since destructive volcanic disturbances have been reported from Japan near the time this phenomenon was seen, it has been thought best to make a special report aside from that which will be given in the monthly Meteorological Notes.—[Sgd.] H. A. FRISE, Observer.

## ANNUAL MEETING ROYAL METEOROLOGICAL SOCIETY.[1]

Mr. C. J. P. Cave, president, in the chair.

* * * The president presented to Mr. W. H. Dines the Symons gold medal for 1914, which the council had awarded him in recognition of his distinguished work in connection with meteorological science.

Mr. Cave, in his presidential address, dealt with the subject of upper-air research. He pointed out that research in the upper air may be [prosecuted] by means of a manned balloon with observer and instrument, or by self-registering instruments sent up in kite, captive balloon, or free balloon. Kites were first used for this purpose by Dr. Wilson of Glasgow, 1749; and also in Arctic expeditions in 1821 and 1836. The box kite and the use of steel piano wire instead of line enabled greater heights to be obtained, and both were adopted by the Blue Hill Observatory in 1895. [See the following historical note.—Ed.]

The use of kites was not taken up in England till 1902, when Mr. Dines flew them from a steamer. After referring to the use of balloons and the ascents made by Glaisher and others, the president said that danger to life in high ascents caused MM. Hermite and Besançon to use a registering balloon in 1893; a free balloon carried a recording instrument, the recovery of the instrument being dependent on the balloon being found after its descent: a height of 9 miles was reached in France, and 13 miles in Germany soon after. He next referred to various types of instruments used in this way, and described Mr. Dines's meteorograph, which is an extremely simple and light instrument. Rubber balloons are generally used, and as they ascend they tell us of the winds above the surface, a special theodolite being used for observing the balloons. The International Commission for Scientific Aeronautics directs the studies for upper-air research, and special days are arranged for international ascents of balloons and kites, stations in various parts of the world taking part in the work. The first great result of these researches has been the discovery that the atmosphere is divided into the troposphere, where the air is in constant movement, horizontal and vertical, and the stratosphere, where turbulent motion seems to cease. The stratosphere begins at about 7.5 miles in these latitudes. The method of investigation is new, but many other results are beginning to come to light, and it seems as though changes of weather do not begin at the surface of the earth, but are dependent upon movements taking place about 7.5 miles up.

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## EVOLUTION OF THE METEOROLOGICAL KITE.

Very few appreciate the precise sequence of items in the evolution of a great invention.

In 1890 (see Proceedings International Conference Aerial Navigation held at Chicago, Aug. 1–4, 1893, p. 315) William A. Eddy, of Bayonne, N. J., began his enthusiastic experiments "to evolve the best form of kites to be used in raising self-recording meteorological instruments to a great height," and fully demonstrated the unrealized possibilities of the kite. In August, 1892, his Malay kite penetrated a shower cloud. In July, 1894 (see American Meteorological Journal, vol. 11, p. 298), at the Editor's earnest suggestion he temporarily transferred his experimental kites to the Blue Hill Observatory, established and maintained by the enthusiastic meteorologist, A. Lawrence Rotch.

On July 13, 1893, Prof. M. W. Harrington wrote the article on pages 203–206 of the American Meteorological Journal, volume 10, expressing his belief that any hope of marked improvement must lie in scientific investigation of the upper atmosphere, which he calls "the free air," by means of kites and balloons. A few weeks later, namely, at Chicago on August 1, he communicated to the International Conference on Aerial Navigation (see p. 349 of the proceedings) his paper on systematic explorations of the upper air, following which (see p. 354, op. cit.) the conference unanimously voted "that Congress should in our judgment make necessary appropriation to have the experiments made as recommended by Prof. Harrington." (See also Monthly Weather Review, Washington, July, 1897, p. 313.) At this same conference Mr. Lawrence Hargrave, of Melbourne, gave an account of his box kites and Mr. William A. Eddy of his Malay kite. (Aeronautics, vol. 1, p. 82, and Monthly Weather Review, 1897, p. 311.) The stimulus thus given at this conference, whose origin was due to Mr. Octave Chanute and Prof. A. F. Zahm, marks the beginning of the official kite work in the Weather Bureau, although it is quite true that its importance had been urged and many experiments had been privately and personally carried out during previous years by numerous officials, e. g., Abbe (1871), Hazen (1890), McAdie (1884), Marvin (1891), Potter (1890), Sherman (1879), Waldo (1882). The abrupt and lamentable dismissal of Prof. Harrington, July 1, 1895, interrupted his plans of cooperation in this work and led to the following order of November 18, 1895, by which Prof. Moore placed all further investigations relative to kite, aeroplane and balloons in the hands of Prof. C. F. Marvin:

WASHINGTON, D. C., *November 18, 1895.*

Prof. MARVIN:

You are hereby directed to investigate the problem of constructing appliances for carrying meteorological instruments into the upper air. Authority will be given you for any reasonable expense necessary for construction of appliances used in experiments. It is hoped that you will give early and thorough attention to this matter. You may consult with Prof. Hazen, if you wish, but I am inclined to think that independent action will be better.

You will also please give your attention to the construction of necessary instruments, but this part of the work is not so important as the making of the aeroplane, or balloon.

Very respectfully,

WILLIS L. MOORE, *Chief of Bureau.*

The account of the work done at Blue Hill, published by A. L. Rotch, January 13, 1897, in the Proceedings American Academy of Arts and Sciences, volume 32, pages 245–251, gives interesting historical items generally gathered from the pages of the Monthly Weather Review. The enthusiasm and energy shown by Eddy, at Bayonne, and Rotch, Clayton, and Ferguson, at Blue Hill, is to be compared only with the steady progress made at Washington in the theory, improvement, and construction of every detail in kite work considered as a problem in economic engineering. While recognizing the innumerable experiments and suggestions that are on record since the first work by Alexander Wilson, in 1749, at Glasgow,

[1] From The Athenæum, London, Jan. 24, 1914, p. 139.

yet we must recognize that the present kites and accessories ordinarily employed in the work are essentially the same as the perfected forms developed by Prof. C. F. Marvin when he was in charge of the investigations from 1895 to 1898.—[C. A.]

## RESULTS OF THE KOCH EXPEDITION ACROSS GREENLAND, 1912–13.

The scientific results of the Koch expedition across Greenland in 1912–13 are presented in abstract by Dr. Alfred Wegener in the Zeitschrift der Gesellschaft für Erdkunde zu Berlin, 1914, No. 1. Among the many subjects investigated on that trip the following will be of interest to our readers.

Temperature measurements of the Ice Cap, made at different depths in borings into the ice, showed that at a depth sufficient to get below the level of annual variations the temperature is about −15° C., departing but very little from the average annual air temperature of the locality. At increasing depths below this level there is a slight but distinctly measurable rise in temperature at the rate of 1° C. per 20 meters. The deepest boring attained a depth of 24 meters below the general surface of the ice. The temperature measurements in general indicate an average air temperature of −32° C. for the central portion of Greenland.

Studies in the granular structure of the snow and of the ice enabled the travelers to determine quite accurately the relative snowfall on either coast and in the interior. At an altitude of 2,000 meters, along either coast, there is no longer any evidence of summer melting of the snow and here the winter snow may be differentiated from the summer fall by the finer-grained structure of the former. The depth of the winter[?] fall decreases from about one-half meter on the east coast to about 30 centimeters in the interior, and then increases westward to its maximum of about 1 meter near the west coast.

A visit to the Jakobshavn glacier in west Greenland showed that this ice stream has receded several kilometers from where its retreating front stood at the time of the last visit.

A meteorological station was established at Borg (22° 12′ W. long., 76° 40′ N. lat.) on the Storstrommen, a great glacial tongue reaching down to the Stors-fjord from the inland ice of Queen-Louise Land. The observations here will prove of particular interest, when published, since they are the first series from a station located on the inland ice proper, and thus will furnish interesting comparisons with the stations Danmarkshavn and Pustervig of the Danmark-Expedition of 1906–8. In passing it is of interest to note that Borg has a mean temperature 5° C. lower than that of Danmarkshavn on the coast, and the precipitation is considerably less.

Special microphotographic investigations were carried out in the forms and structure of the various ice crystals met with at Borg; and the aurora was successfully photographed many times. Observations on the three twilight arches resulted in determinations of the altitude of the so-called geocoronium sphere, the most distant observable evidences of our atmosphere, at 600 kilometers. With these observations on the twilight arches go necessarily efforts to identify the zodiacal light, and Wegener succeeded in doing so even at this very high latitude. This is probably the first set of observations of the zodiacal light from a point so near the earth's poles.

Not least interesting among the results of this expedition are the observations on polarization of blue sky light, and the discovery that even as late as the spring of 1913 the Babinet and Arago neutral points still showed in those latitudes an observable though weak influence of the optic-atmospheric disturbance of 1912. Wegener even succeeded in securing for the first time photographic records of the interference bands, or "Polarisationsstreifen" appearing in the field of his Savart-Jensen polariscope.

Undoubtedly the publication in full of these Greenland observations (perhaps in "Meddelelser om Grönland") will give most interesting details to both meteorologists and geographers.—[C. A. JR.]

## OBSERVATIONS OF EARTHQUAKES.

The Secretary of Agriculture has received from the Secretary of State an interesting report on the earthquake of January 15, 1914, at Leghorn, Italy. Unfortunately, a recent decision of the comptroller forbade the Weather Bureau to utilize its important apparatus for the observation and record of earthquakes, until the Weather Bureau is specifically authorized by Congress to engage in seismological work. The Editor believes there is no other institution in the country so well qualified as the Weather Bureau to carry on this important work.—[C. A.]

## SECTION III.—FORECASTS.

### STORMS AND WARNINGS FOR JANUARY.

By H. C. FRANKENFIELD, Professor of Meteorology.

[Dated Feb. 5, 1914.]

At the beginning of the month a high-pressure area with a cold wave was passing down the St. Lawrence Valley. There was a low area between the Carolinas and Bermuda and another of decided proportions over the Dakotas. There had not been much precipitation over the East during the preceding 24 hours, but in the Northwest and over the section west of the Rocky Mountains there had been quite general rains and snows. The winds were increasing on the north Atlantic coast, and storm warnings were ordered in the morning from Boston to Elizabeth City, N. C. At the same time advices of snow or rain with high southerly winds were sent to open ports on Lake Michigan. Temperatures were high throughout the country, except from the lower Lake region eastward; abnormally so in the Rocky Mountain region and the Northwest. During the 1st pressure also fell on the north Pacific coast, and storm warnings were ordered from Point Lobos, Cal., northward. By the morning of the 2d the northwestern low area had reached the upper Mississippi Valley with an offshoot over Louisiana, and general snows and rains had fallen throughout the central valleys and the upper Lake region. High pressure, low temperature, and high winds continued to the northeastward, while the north Pacific storm was approaching the Washington coast with much increased energy. Over the Plateau region pressure was high. Cautionary advices for snow and colder high winds were again ordered for Lake Michigan ports, and small-craft warnings were ordered along the eastern Gulf of Mexico. During the next 24 hours the upper Mississippi Valley low extended eastward to southern Michigan, while the secondary depression that had been over Louisiana had moved to North Carolina with a great increase in intensity, and general snows and rains had fallen east of the Mississippi River and continued generally, except in the east Gulf and South Atlantic States. Temperatures had fallen considerably over the Gulf States and the Southwest, but were not unusually low. They had also risen decidedly in the Atlantic States. During the afternoon of the 2d storm warnings were ordered on the Gulf coast from Tampa to Pensacola and on the Atlantic coast from Jupiter, Fla., to Charleston, and during the evening and the following morning they were extended along the entire Atlantic coast north of Jupiter, with northeast warnings from Delaware Breakwater to Eastport. In the meantime the Pacific low area had moved to Alberta, and warnings were extended southward to Port Harford, Cal., and continued to the northward, although pressure was rising. There was now a moderate high area over Texas, and warnings were ordered in Louisiana for the frost that occurred on the following morning. Warnings of frost and freezing temperatures were also ordered for South Carolina, Georgia, Alabama, Mississippi, and northern Florida, and warnings of frost for central Florida, and on the following morning freezing temperatures and frosts occurred as forecast.

On the morning of the 4th the southern section of the storm had reached New Jersey, while the northern one had disappeared, but snows and rains continued north of Tennessee and east of the Mississippi River with strong northeasterly gales on the New England coast, and storm warnings were continued from Baltimore northward. There was an extensive high area over Lake Superior, the Mississippi and Missouri Valleys, and the extreme central West, but without low temperatures in the United States; and another disturbance had reached the north Pacific coast accompanied by southerly gales and rains. Storm warnings had been continued on the 3d north of San Francisco, and they were again continued on the 4th. Cold-wave warnings were also ordered for New England and the northern portion of eastern New York and warnings of freezing temperatures or frost in Alabama, Georgia, South Carolina, and Florida. The frosts and cold wave occurred as forecast, but the latter was delayed until the morning of the 6th, by which time the north Pacific storm had reached northern Lake Superior and another was just crossing British Columbia, while over the central and southern portions of the country pressure was high but still without low temperatures. There had been no precipitation of consequence except in the north Pacific States. Winds on the Atlantic coast had subsided, and warnings were finally lowered on the New England coast. They were, however, continued on the north Pacific coast, as another low-pressure area covered that locality. It should have been remarked that considerable snow had fallen over the central Rocky Mountain region, and a high-pressure area that formed over western Colorado during the 2d persisted with minor fluctuations and with low temperatures until the 15th, when low pressure from the West took its place. By the morning of the 7th the Lake Superior low area had reached the Gulf of St. Lawrence, accompanied by light local snows from the Lake region eastward.

The British Columbia low had reached Winnipeg with increased development but without precipitation, and its place had been taken by another that had moved in from the north Pacific Ocean, and for which storm warnings had already been ordered. Cold weather continued in the South with more heavy frosts in northern Florida and along the Gulf coast. Over the remainder of the country, temperatures were still above the seasonal average.

On the morning of the 8th there had been a general decided fall in pressure throughout the country, except in the Pacific States, with the principal center of depression over Iowa, but the weather was without unusual incident except that there were more frosts in Florida and along the Gulf coast for which warnings had been ordered on the previous day. On the morning of the 9th the Iowa low had moved to southeastern Michigan with increased intensity, and pressure was low everywhere, except in the Pacific States. Small-craft warnings were ordered on the east Gulf coast, also from Charleston to Norfolk,

and advisory messages of strong winds with snow and cold weather were sent to open ports on Lake Michigan. During the afternoon southwest storms warnings were ordered from Sandy Hook to Eastport. By the morning of the 10th the Lake storm had reached the Nova Scotia coast with a great increase in intensity (the barometer at Sydney reading 28.80 inches) and light snows had fallen from the upper Mississippi Valley eastward. There was another disturbance of indifferent character near the mouth of the Rio Grande, another over Saskatchewan, and still another of more important character was approaching the Pacific Northwest, necessitating the hoisting of storm warnings on the north Pacific coast; at the same time warnings were continued on the New England and middle Atlantic coasts. Pressure was rising rapidly in the central West, and during the night cold-wave warnings were ordered for eastern Wisconsin, northeastern Michigan, and northern New England.

On the morning of the 10th warnings of frost and freezing temperatures were again issued for the South Atlantic and Gulf States, including Florida, and also for California and southeastern Arizona. On the morning of the 11th the eastern storm was passing over the Newfoundland coast with a barometer reading of 28.42 inches at St. Johns, and a moderate cold wave covered the districts from Lake Huron eastward. Low temperatures continued in the South but without much precipitation, and another low area from the Northwest had reached Lake Superior with a considerable increase in intensity. On account of the latter disturbance, and on account of a cold high area then central over northern Saskatchewan, advisory warnings of brisk to high northwest winds with a cold wave were again sent to Lake Michigan ports, and cold-wave warnings were ordered for Minnesota. During the day of the 11th the northwestern high area developed rapidly, and in the afternoon cold-wave warnings were ordered for the upper Lake region, the upper Mississippi Valley generally, South Dakota and northern Nebraska. Warnings were also issued for frost in Florida, and freezing temperatures in South Carolina and Georgia. Small-craft warnings were also ordered in the morning at Key West, and at night southwest storm warnings were ordered on the Atlantic coast from Sandy Hook to Eastport. Storm warnings had also been continued on the north Pacific coast and were extended southward to San Francisco.

On the morning of the 12th a strong high-pressure area covered the Northwest, and pressure was generally high over the upper Lake region, the central valleys, and in the South and the interior West. The Lake Superior disturbance had reached the St. Lawrence Valley with much increased intensity, and general snows had fallen from the Ohio Valley and Lake region northeastward. There had been severe gales on the Lakes and a cold wave covered the entire northern portion of the country east of the Rocky Mountains, except the northeast. Temperatures also fell considerably in the South, with more heavy frosts and freezing temperatures. Storm warnings were then continued southward on the Atlantic coast as far as Norfolk. The north Pacific disturbance had also increased somewhat, and on the evening of the 12th storm warnings were continued from San Francisco northward and extended southward to San Diego. By the following morning (13th) the storm center had passed off the Newfoundland coast and a severe cold wave prevailed from Ontario eastward with temperature readings of 48° below zero at White River, Canada, and 24° below zero at Northfield, Vt. Warnings for the sections of the United States covered by the cold wave had been issued on the morning of the 12th. Pressure was now high everywhere east of the Rocky Mountains, except in New England, and temperatures were below the seasonal average throughout the eastern half of the country. Pressure was still low on the Pacific coast and storm warnings were continued from Eureka to San Francisco.

By the morning of the 14th there had been a further fall in temperature in the Atlantic States and the line of zero extended to extreme southern New Jersey, while at Canton, N. Y., the thermometer registered 30° below zero. Pressure, however, was falling rapidly in the West and there had been a general and decided rise in temperatures to much above normal conditions. Pressure had also again fallen on the Pacific coast and storm warnings were ordered generally from San Diego northward. A Canadian northwest disturbance of considerable energy had reached Manitoba and advisory messages were sent to Lake Michigan ports. By the evening of January 14 the Manitoba disturbance had reached northern Lake Superior, and southwest storm warnings were ordered from Delaware Breakwater to Boston. However, by the morning of the 15th this disturbance had lost much of its intensity and had moved very little; consequently there were no high winds on the Atlantic coast and storm warnings were ordered down at 10 a. m. Light local snows had continued from the Lake region eastward and there had been a great rise in temperature over practically the entire country, so that in the Northwest and extreme Central West temperatures were 20° to 35° above the seasonal average. The north Pacific storm of the previous day had moved to Saskatchewan and another was approaching the Washington coast, necessitating a continuance of the storm warnings from San Francisco northward. Rains and snows also continued generally west of the Rocky Mountains. By the morning of the 16th the northwestern disturbance had reached Lake Michigan with increased intensity but without precipitation, except snow in the Lake Superior region. The Pacific disturbance continued to increase, rains and snows were still general, and storm warnings were continued generally northward of San Francisco and extended southward to San Diego. Over the interior of the country pressure was comparatively low, but with high temperatures and without precipitation. On the morning of the 17th there was a strong high area over Lake Superior with some quite low temperature readings in Canada. The low area had passed off the southern New England coast and there had been quite general snows from the Lake region and upper Ohio Valley eastward. Snows and rains also continued west of the Rocky Mountains. The barometer continued to fall on the north Pacific coast and the lowest readings thus far in the month were recorded, Roseburg, Oreg., reporting 29.14 inches at 8 a. m.

By the morning of the 18th pressure was low west of the Rocky Mountains and in the Northwest, with the lowest barometer off the Washington coast, and rains and snows had fallen generally west of the mountains. Conditions were also unsettled over the central portion of the country, with some snow, while to the eastward pressure was high with much lower temperatures and with a moderate cold wave over the northeastern districts. On the morning of the 19th there was a depression of indefinite character over Minnesota and Lake Superior without precipitation of consequence and pressure was rising rapidly to the northwestward, the low area off the Washington coast having almost entirely disappeared, although general rains and snows continued west of the mountains. The main disturbance drifted eastward in irregular formation, causing rains and snows from the upper Mississippi Valley and

upper Lake region eastward and some snows in the Northwest. Directly to the northward pressure was rising rapidly with a decided fall in temperature, while to the southward the weather was unsettled and abnormally warm, with falling pressure. Over the extreme Central West pressure was high with seasonable temperatures, but another low was approaching the north Pacific coast and rains and snows were again falling in Idaho, Oregon, and Washington. By the evening of the 20th the Middle West storm had assumed definite character with increased intensity and snows and rains were falling generally from the upper Mississippi Valley and the upper Lake region eastward, while to the southward the weather continued generally fair with abnormally high temperatures. Small craft warnings were ordered for the following day from Norfolk to Boston and southeast storm warnings on the Oregon and northern California coasts. By the morning of the 21st the eastern storm had reached New York and southern New England with still further development, and storm warnings were at once ordered from Eastport, Me., to Hatteras, N. C. The barometer had also continued to fall to the southward and rains and snows had occurred generally over the eastern half of the country. In the Central West the weather was still fair with moderately low temperatures, while west of the Rocky Mountains the barometer continued to fall with general snows and rains over the central and northern districts, and storm warnings were ordered during the day for the remainder of the north Pacific coast and were continued on the north California coast. During the next 24 hours the eastern storm moved off the Newfoundland coast with a still greater increase of energy and the weather had cleared generally throughout the Atlantic and Gulf States with a decided fall in temperature, and with a cold wave in New York and New England.

The north Pacific storm had moved inland and conditions had become very much unsettled west of the Allegheny Mountains with five or six separate centers of depression, and with light snows in the Lake region, the central valleys, and the extreme Northwest. Rains and snows also continued over the northern and middle districts west of the Rocky Mountains with heavy rainfall in many portions of northern California. The rains and snows continued over the extreme West, but the low-pressure conditions drifted eastward so that on the morning of the 23d there was a well-defined disturbance over southwestern Iowa and another over Lake Superior, while in the Atlantic States the weather remained generally fair with low temperatures over the northern districts. On the morning of the 24th unsettled weather prevailed from the Mississippi Valley eastward with general rains and snows and with another decided rise in temperature, while over the Northwest pressure was rising rapidly with a cold wave, the temperatures ranging from 4° to 20° below zero, while in the Canadian Northwest they were as low as 34° below zero. Rains continued in the Pacific States and another decided fall in pressure occurred, the barometer at Roseburg, Oreg., reading 29.24 inches.

As conditions were threatening in the East storm warnings were ordered on the Atlantic coast from Jacksonville to Eastport and during the following 24 hours high winds occurred generally. Similar conditions prevailed in the Pacific districts on the following day and a low area that had been over the Ohio Valley moved rapidly northeastward to New Brunswick with a decided increase in intensity. As pressure was again falling rapidly throughout the West unsettled weather generally continued throughout the country. Conditions then became more settled east of the Rocky Mountains although light rains and snows continued in the central valleys and the Lake region, but the Pacific storm continued to increase, and at 8 p. m. of the 25th the reduced barometer at Tatoosh Island, Wash., read 28.60 inches, rising to 28.80 inches by the following morning. Low pressure now prevailed generally except in the Northeast, with a second center of abnormally low pressure over western South Dakota, and conditions were unsettled with rains and snows over all districts except the central Rocky Mountain region and the Southwest. Over much of central and southern California the rainfall was torrential.

On the morning of the 27th high pressure prevailed in the Atlantic States, but was still generally low over the Interior, although with somewhat more settled conditions. There was a depression over Iowa that during the following 24 hours moved northeastward to New Brunswick with decreasing intensity causing some light snows and rains in the lower Lake region and New England, while the Pacific disturbance had moved rapidly to the eastern slope of the Rocky Mountains and high pressure prevailed in the Coast States. Up to this time storm warnings had been displayed continuously on the Pacific coast. The weather remained unsettled but without much precipitation east of the Rocky Mountains except in the northwestern States. Owing to the rapidly falling pressure small craft warnings were ordered on the morning of the 28th for the Gulf coast from Brownsville, Tex., to Carrabelle, Fla. There had also been a decided rise of pressure over British Columbia accompanied by a cold wave and cold wave warnings were ordered for the Northwest and Central West generally. By the morning of the 29th the western disturbance was central over northern Lake Superior with greater intensity, but at the same time a secondary offshoot had moved from southeast Colorado to the mouth of the Rio Grande with an apparent decrease in energy. A rapid rise in pressure and an equally rapid fall in temperature followed this low, and snows and rains occurred from Texas northeastward through the upper Lake region. Temperatures remained abnormally high throughout the East and South and cold wave warnings were ordered for the Ohio Valley. Pressure had also risen west of the Rocky Mountains, except on the north coast, and temperatures were generally low with frosts in California. As pressure was again falling on the Washington coast, storm warnings were ordered for Washington and Oregon.

By the morning of the 30th the northern disturbance had reached the Gulf of St. Lawrence practically dry. The one that had been over the mouth of the Rio Grande had moved to southeastern Mississippi, while the Pacific storm had moved inland to Saskatchewan attended by snows and rains over the extreme Northwest. In the upper Lake region, the central valleys, and in the extreme West pressure was high with low temperatures as a rule, but in the East and South abnormally high temperatures continued, and snows and rains were falling in the Ohio Valley and the Gulf States. The northern storm passed off the Newfoundland coast by the morning of the 31st and the northwestern one had moved to western Lake Superior without incident, but the southern storm had developed great intensity and had reached northeastern Ohio, with a barometer reading 29.44 inches at Cleveland. Heavy rains fell over the middle and south Atlantic States and heavy snows and rains in the Ohio Valley, the lower Lake and southern upper Lake regions. In the West the weather was generally clear with high pressure and moderate temperatures except

on the north Pacific coast, where snows and rains were again falling with lower pressure. Owing to the threatening conditions on the night of the 30th cautionary advices were sent to Atlantic coast ports from Baltimore to Boston, and on the morning of the 31st storm warnings were ordered from Hatteras to Eastport, and at the same time warnings of heavy frost and freezing temperatures were sent to the Southern States as far south as northern Florida. On the night of the 31st the disturbance covered Ontario, New York, and southern New England, with general rains and snows and high winds over those sections, but in the interior the weather had cleared except in the upper Lake region and temperatures were falling rapidly but not to any low figures.

### NORTHERN HEMISPHERE PRESSURE DISTRIBUTION.

Over Alaska pressure was low throughout the first half of the month, abnormally so during much of the time, while during the second half of the month the reverse condition prevailed except between the 27th and 30th, and there were marked crests between the 20th and 23d.

Over the United States there was the usual progression of low and high areas of fairly uniform character during the first half of the month, but during the second half low pressure predominated without the intervention of any marked high areas, the result being apparent in the abnormally high temperatures that prevailed throughout much of the month. There was quite a severe storm during the last day of the month, but it did not develop materially until that time.

Over the Canadian Maritime Provinces pressure appears to have been abnormally low much of the time. There were, however, quite well-marked crests of high pressure on the 3d and again on the 27th and 29th.

Over the western half of the north Atlantic Ocean pressure was also low during much of the month with a decided fall over the island of Bermuda and over the Azores on the 17th. There was some recovery, however, during the third decade of the month. Over the eastern portion of the north Atlantic the opposite conditions prevailed and high pressure was general up to the 22d, except between the 4th and the 10th, with maximum pressure on the 13th and 15th, inclusive. After the 22d a period of low pressure set in which was exceedingly well marked over Iceland, especially on the last day of of the month, when the barometer at Seydisfiord read 962 millibars, or 28.42 inches.

Over Europe—that is, western Europe—there was considerable high pressure with rather low temperatures, although a decided depression occurred on the 5th and 6th. Over Russia pressure was generally low, frequently abnormally so, with but a single period of marked high pressure from the 11th to the 13th of the month. Low pressure also prevailed to the eastward throughout Siberia without any intermissions of importance.

In the coast districts, including Japan and China, fluctuations were within comparatively narrow limits, except from the 13th to the 15th, when there was a marked depression.

In the north Pacific Ocean conditions were very much similar to those that prevailed over Alaska, that is, low pressure during the first half of the month and generally high during the second half, with marked departures from the normal in both directions. As was to be expected the opposite conditions prevailed over the southern portion of the north Pacific as indicated by the reports from Honolulu, where moderately low pressure during the first five days of the month was succeeded by a period of high pressure which lasted until the 17th, with a strong crest on the 15th. Afterwards there were four or five days of nearly normal pressure followed by a period of high pressure that prevailed until the last day of the month. Opposite conditions prevailed over the north section at the same time, but not to such a marked extent as during the first half of the month.

Beginning with the 30th day of the month reports from Spitzbergen were added to the International Weather Chart, which began publication on January 1, 1914.

# SECTION IV.—RIVERS AND FLOODS.

## THE RIVERS DURING JANUARY.

By ALFRED J. HENRY, Professor of Meteorology.

With few and mostly unimportant exceptions, the rivers were well within their banks during January, as may be read from Chart I, Hydrographs for typical points on several of the principal rivers.

### FLOODS IN THE RIVERS OF SOUTH CAROLINA.

The Wateree at Camden, S. C., was 3.1 feet above the flood stage on the 4th, and the Santee at Rimini, S. C., was above the flood stage from the 1st to the 12th, inclusive.—*Report of Richard H. Sullivan, Section Director.*

*The Pedee River.*—The Pedee was in flood on January 4, cresting at a stage of 29.5 feet at Cheraw, due to heavy rains over the watershed. At Smiths Mills, the next station below Cheraw, the flood stage was not reached.

No appreciable damage was caused in the upper reaches of the river, but in the lower reaches much stock was driven out and thus saved by the warnings that were issued.—*Report of J. H. Scott, Local Forecaster.*

### FLOODS IN RIVERS OF NORTH CAROLINA.

The Roanoke River at Weldon, N. C., was 3.5 feet above the flood stage (30 feet) on the 6th. This flood soon subsided. The Cape Fear River at Elizabethton, N. C., was above flood stage on the 5th, 6th, and 7th. The Neuse River was above the flood stage on the 4th and 6th, at Neuse, N. C. Both floods were of short duration.—*Report of Lee A. Denson, Section Director.*

### FLOOD IN THE SUSQUEHANNA RIVER.

The lower portion of the North Branch of the main river was frozen in places about the end of December, 1913. There were, however, long stretches where the main channel remained open, with ice extending out some distance from the shore.

Warm weather on the 27th and 28th of January caused melting of the snow that had accumulated in the Susquehanna basin; and during the afternoon of the 29th a general breaking up of the ice began on the Chemung, the North Branch, and upper portions of the West Branch.

The ice broke up at Clearfield at 1.30 p. m. of the 29th, moving out on 4.5 feet of water. At Renova, Pa., the ice broke at 2.50 p. m., and passed out on a flood of 11 feet on the same date. At a later date, January 30, the ice passed Williamsport at a stage of 14.5 feet.

No ice gorges formed in the North Branch, the stages being high enough to carry the ice out.

Rain on January 31 complicated the situation somewhat, but the run-off was not sufficient to produce flood stages. No damage was occasioned.—*Report of E. R. Demain, Local Forecaster.*

### THE FLOODS IN THE SACRAMENTO AND SAN JOAQUIN.

The Sacramento and its tributaries were in flood several times during the month, due to heavy rains and melting snows. On the upper stretches of the stream, as at Red Bluff, the river passed above the flood stage on the 1st, and crested at a stage of 29 feet, 6 feet above the flood stage. This flood wave also produced gage readings above the flood stage at Nicolaus on the Feather, Kennett, Jacinto, Colusa, Knights Landing, and Rio Vista, on the Sacramento; but at Sacramento the flood stage was not reached. The essential statistics of the floods in the Sacramento and San Joaquin Rivers will be found in the table below.

The rainfall in the watershed, while not unusually heavy, occurred in frequent short periods, and as a result there were a number of minor wave crests during the second half of the month, with a steadily rising river, culminating in a stage of 27.8 feet at Sacramento on the 28th. By the end of the month the flood had passed, and the headwater tributary streams were falling. The high water caused a number of breaks in the levees, and an extent of land estimated at 60,000 acres was flooded.—(*After N. R. Taylor, Local Forecaster.*)

*Flood in the upper San Joaquin.*—The first general flood in several years occurred simultaneously in all streams of the upper San Joaquin watershed on the 24th, and culminated on the following day on the Merced River in the highest stage recorded during a period of eight years. Likewise, the highest stage recorded on the San Joaquin at Friant in a period of eight years occurred at midnight of the 25th. In Kings River probably no flood of similar proportions has occurred within the last fifty years.—(*After W. E. Bonner, Local Forecaster.*)

TABLE 1.—*Statistics of floods during January, 1914, in the Sacramento and San Joaquin Rivers.*

SACRAMENTO RIVER.

| Station. | River. | Highest stage. | | Above or below flood stage. | Rainfall. |
|---|---|---|---|---|---|
| | | Reading. | Date. | | |
| | | *Feet.* | | *Feet.* | *Inches.* |
| St. John | Stony Creek | 10.0 | 1st | −2.0 | 8.91 |
| Colgate | Yuba | 11.8 | 25th | −2.2 | 19.30 |
| Marysville | ....do | 21.5 | 1st | −6.5 | 5.80 |
| Oroville | Feather | 22.0 | 1st | −3.0 | 12.53 |
| Nicolaus | ....do | 23.0 | 1st | +2.0 | 8.14 |
| Folsom | American | 18.8 | 25th | ..... | 12.14 |
| Kennett | Sacramento | 25.4 | 2d | +0.4 | 25.58 |
| Red Bluff | ....do | 29.0 | 1st | +6.0 | 9.50 |
| Jacinto | ....do | 23.0 | 2d | +2.0 | 8.09 |
| Colusa | ....do | 28.3 | 4th | +0.3 | 6.97 |
| Knights Landing | ....do | 18.9 | 5th | +0.9 | 9.21 |
| Sacramento | ....do | 27.8 | 27th | −1.2 | 5.97 |
| Rio Vista | ....do | 13.6 | 28th | +0.6 | 9.54 |

SAN JOAQUIN RIVER.

| | | | | | |
|---|---|---|---|---|---|
| Piedra | Kings | 21.8 | 25th | +9.8 | ..... |
| Merced Falls | Merced | 10.3 | 25th | +3.3 | ..... |
| Friant | San Joaquin | 12.4 | 25th | +4.4 | ..... |
| Firebaugh | ....do | 11.4 | 28th | −0.6 | ..... |
| Lathrop | ....do | 19.7 | 27th | +2.7 | 5.79 |
| Bensons Ferry | Mokelumne | 13.1 | 27th | +1.1 | 9.40 |
| Electra | ....do | 8.5 | 20th | −3.5 | 14.45 |
| Bellota | Mormon Slough | 20.3 | 18th | +0.3 | 8.62 |
| Jenny Lind | Calaveras | 6.0 | 22d | −4.0 | 8.21 |
| Melones | Stanislaus | 6.2 | 25th | ..... | 13.44 |
| Jacksonville | Tuolumne | 24.0 | 26th | +1.0 | 14.85 |

TABLE 2.—*Money loss by floods of January, 1914.*

| District. | Tangible property loss, buildings, highways, etc. | Farms and farm property, including prospective crops. | Stock and movable property. | Total. |
|---|---|---|---|---|
| South Carolina | | | $400 | $400 |
| California: | | | | |
| Sacramento | $370,000 | $200,000 | 1,000 | 571,600 |
| San Joaquin | 80,000 | 5,500 | 600 | 91,000 |

Hydrographs for typical points on several principal rivers are shown on Chart I. The stations selected for charting are Keokuk, St. Louis, Memphis, Vicksburg, and New Orleans, on the Mississippi; Cincinnati and Cairo, on the Ohio; Nashville, on the Cumberland; Johnsonville, on the Tennessee; Kansas City, on the Missouri; Little Rock, on the Arkansas; and Shreveport, on the Red.

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## FRESHETS IN THE SAVANNAH RIVER

### AND THE FORECASTING OF HIGH WATER AT AUGUSTA, GA.

By EUGENE D. EMIGH, Local Forecaster, Augusta, Ga.

[Dated May 16, 1913; revised December, 1914.]

### PREFACE.

This paper is chiefly an explanation and discussion of the river forecast scheme that is used successfully by the writer in predicting high river stages for the benefit of the business and residential interests of Augusta, Ga., and the river farmers, lumbermen, and navigators below Augusta. It is hoped it may prove helpful to river forecasters elsewhere, and interesting to students of river flow.

Acknowledgements are due and are gratefully extended to Profs. H. C. Frankenfield and A. J. Henry, and Mr. H. W. Smith, of the Central Office of the Weather Bureau, Messrs. M. R. Hall and W. E. Hall of the United States Geological Survey, Judge Henry C. Hammond, of Augusta, Hon. Nisbet Wingfield, chief engineer of the river and canal commission of Augusta, and others who have furnished valuable historical and scientific facts and publications, as well as to the office force of the Augusta office of the United States Weather Bureau for assistance on tabular matter and diagrams.

### THE SAVANNAH RIVER.

The Savannah River is a stream bold in all of its features. It is formed by the junction of the Seneca and Tugaloo Rivers about 100 miles above Augusta, Ga. The headwaters of the Seneca River are small streams having their origin chiefly in the mountains of South Carolina. The Tugaloo River results from small streams that rise for the most part in the mountains of north Georgia. Numerous creeks and small rivers enter these tributaries and the other tributaries of the Savannah River as well as the main stream. On the South Carolina side, Rocky River, Little River, and Stevens Creek are the most important streams, while on the Georgia side are found the Broad River, which is the largest of the tributaries, and the Little River, another important stream.

Por its size the Savannah River is an unusually restless stream, sensitive to even small amount of rainfall and subject to frequent rises. Here rushing in cascades over the granite bed, there resting in placid shoals, the the water makes on the whole rapid progres; the total fall in 64 miles immediately above Augusta is 257 feet The course is somewhat irregular and islands are quite numerous in the channel. The last of the cascades begins about 6 miles above Augusta and ends at Augusta, below which point navigable waters move leisurely along a winding course through the low swamps of the Coastal Plain to the Atlantic Ocean. It has been estimated that the Savannah River and the streams tributary to it are capable of generating a minimum of 200,000 horsepower, of which but a small amount is developed.

#### *Topography and Geology.*

Practically all of the catchment basin of the Savannah River above Augusta occupies the Piedmont Plateau. It is characterized by a truly rugged topography of clay hills overlying geologic formations of granite and gneiss. Elevations range from about 200 feet above sea level at the eastern edge of the plateau to 1,000 feet on its western edge. In remote mountain districts the general altitude is about 2,000 feet, with prominences considerably higher. The area of the watershed is 7,294 square miles.

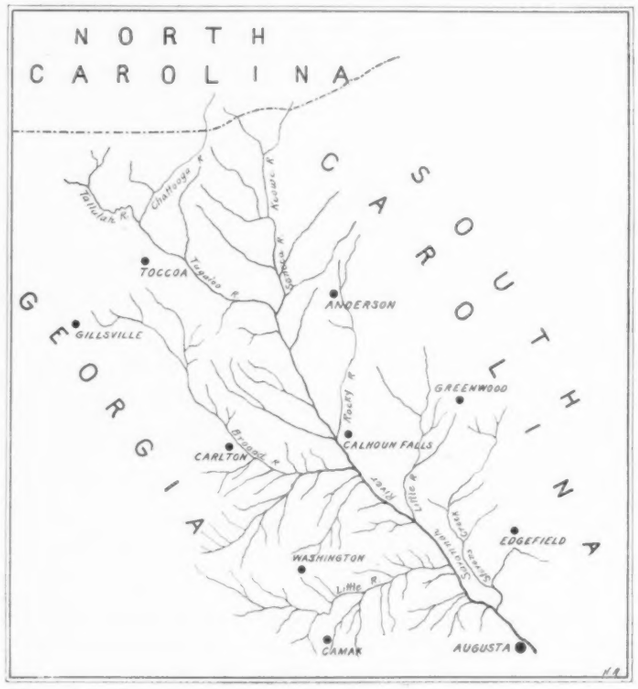


FIG. 1.—The Savannah River watershed above Augusta, Ga. Area 7,294 square miles.

#### *Forestry conditions.*

The South Carolina State Department of Agriculture, Commerce and Industries has published "Bulletin 1, January, 1910. Forest conditions in South Carolina. Report of Preliminary Examination and Survey. By W. M. Moore, forest assistant, United States Bureau of Forestry, Columbia, S. C., 1910." This report gives a description of past and present forest conditions that applies to the Savannah River watershed. The following is copied from his report:

*Alpine region*—Only about 25 per cent of this region has been cleared of forest, and many fields that have been cleared have after

wards been abandoned. Red oak, blackjack oak, black oak, chestnut, black locust, scrub pine, and shortleaf pine are the principal trees of the higher altitudes. At the highest elevations white pine, hemlock, and fir are sometimes found, this being practically the southern limit of their range. On the lower slopes are found white, post, blackjack, swamp white, and red oaks, red and mountain maples, hickories, chestnut, black walnut, butternut, black locust, sweet gum, black gum, tulip poplar, basswood, white ash, red cedar, and shortleaf, scrub, and pitch pines. The oaks form a large part of the stand. The undergrowth consists largely of small seedlings and sprouts of the species mentioned, together with mountain laurel, rhododendron, huckleberries, blackberries, and asters and other herbaceous plants. There is not much grass, but ferns, mosses, and liverworts abound.

*Piedmont region.*—The entire Piedmont region was once well forested, though only about 25 per cent is in forests now. This is natural, since the region is distinctly agricultural, and the climate is healthful and invigorating throughout the year. The forest which remains is largely on rough land, along river courses, and in farm wood lots. The prevailing forest consists principally of short-leaf pine. Mixed with the pine in varying proportions and in various localities were oaks, such as white, post, overcup, chestnut, scarlet, black, shingle, and blackjack, chestnut, black walnut, black locust, sweet gum, black gum, ash, basswood, and tulip poplar. The most common trees along the river courses are sweet gum, sycamore, tulip poplar, black willow, white oak, post oak, and shortleaf pine. Gum, sycamore, and tulip poplar reach large size.

Wood lots of various sizes are well distributed throughout the Piedmont region, since a portion of nearly every farm has been kept in timber. The most abundant tree in these wood lots is shortleaf pine, known also as "woods pine" and "heart pine." It sometimes grows in pure stands, but it is generally mixed with oaks, hickories, and other hardwoods. Shortleaf pine is a prolific cone bearer and a quick seeder. Wherever fires are kept out its reproduction is excellent, and young seedlings are found in nearly every wood lot, though they do not thrive in deep shade. Many fields which were abandoned 40 or 50 years ago have grown to dense stands of this pine, which is now of merchantable size. Fields that are occasionally abandoned now because the topsoil is washed away are soon covered with thickets of short-leaf pine.

Since the roots form a network which holds the soil in place the tree is of great value on eroding hillsides. A good illustration is furnished by a field in Greenville County, S. C., which had been cultivated up to 20 years ago. The present owners kept out fires and piled brush in the gullies which were forming. The hillside field is now thickly covered with pines about 20 feet high, the largest of them being 7 inches in diameter. The crown cover is practically continuous and a dense mat of needles on the ground makes forest conditions complete. Tulip poplars are now beginning to come on.

## RELATION OF FORESTS TO STORAGE AND CONSERVATION OF WATER.

A dense cover of forest, principally of pine, has been described as having blanketed the Savannah River watershed. The effect of such a forest upon the storage and retention of water for the future use of streams may be summarized as follows:

1. Considerable quantities of water caught and held in suspension by the trees and undergrowth are returned directly into the air by evaporation. The total loss on this account in the course of a year is fully worthy of mention.

2. Much of the water which penetrates through the trees runs off on the steep slopes that characterize the region.

3. A portion of the rain water passes through the needle mulch and forest humus and augments the groundwater supply.

4. The greatest and most far-reaching loss of soil water so far as the maintenance of stream flow is concerned is due to transpiration by the trees and plants of the forest. Penetrating in all directions and reaching deep into the ground, the roots take up vast quantities of water, which pass through the trunks, branches, and foliage to sustain plant life and promote growth and is evaporated.

5. Considerable loss of moisture occurs through evaporation from the forest floor.

Compared with the great losses occasioned by transpiration, the depletion of soil moisture by evaporation from the surface of the forest soil is, of course, of minor importance. It is, however, very persistent in this southern climate, and its volume depends upon this fact rather than upon great intensity. Undoubtedly the total evaporation from bare uncultivated land in the open in hot weather is as great or greater than from the forest humus, and in cool weather decidedly greater.

In recent years valuable investigations and experiments have been carried on by the United States Department of Agriculture, which are of interest in the consideration of any subject bearing upon the storage and conservation of moisture by the soil. It is interesting to note what these investigators have learned regarding the evaporation of moisture from the soil under different conditions.

The following is quoted from Dry Farming, by J. A. Widtsoe:

> It is an important fact that very dry soil furnishes a very effective protection against the capillary movement of water. In localities where the relative humidity is low, the temperature is high, and the sunshine abundant, evaporation may go on so rapidly that the lower layers can not supply the demand made upon it and the top soil then dries out so completely as to form a protecting covering against further evaporation.
>
> Direct sunshine is, next to temperature, the most active cause of rapid evaporation from moist soil surfaces. Whenever, therefore, evaporation is too slow to form a dry protecting layer of top soil, shading helps materially in reducing surface losses of soil water. Under very arid conditions, however, it is questionable whether in all cases shading has a really beneficial effect, though under semiarid and subhumid conditions the benefits derived from shading are increased largely.
>
> A special case of shading is the mulching of land with straw or other barnyard litter, or with leaves, as in the forest. Such mulching reduces evaporation, but only in part because of its shading action, since it acts also as a loose top layer of soil matter, breaking communication with the lower soil layers.
>
> Whenever the soil is carefully stirred, as will be described, the action of shading as a means of checking evaporation disappears almost entirely. It is only with soils that are tolerably moist at the surface that shading acts beneficially.

To avoid possible misinterpretation of the pages to follow, it will be well to lay stress upon the fact that there is a great difference between mere deforestation and deforestation attended by agricultural development. The former leaves the ground hard and bare and in a condition opposed to the absorption and conservation of moisture; the latter, especially under climatic conditions conducive to perennial cultivation, improves the ground water flow. In a hilly country, such as characterizes the Piedmont section of the Savannah Valley, terracing and advanced methods of cultivation have failed to overcome the tendency for freshets to increase with deforestation, while very active surface run-off results when the fields are uncultivated. In a denuded mountain region, with precipitous slopes, the run-off is extremely flashy, the freshets being torrential and the normal flow deficient. Nothing in this article should, therefore, be construed as an argument against the protection of forests in mountainous sections.

Forester W. M. Moore, in his report on South Carolina above quoted, says:

> The forests of the Alpine region are really protection forests and should be retained as such. The only way to protect the headwaters of the rivers and to prevent further damage to bottom lands, highways, bridges, and mills is for the Federal or State Government to purchase and manage the mountain forests.

In this view the writer entirely concurs.

## CULTIVATION.

In the early days deep plowing was unknown in this section. Since then not only has there been an almost continuous increase in the area of agricultural lands, but

farming methods have greatly improved. Practically all of the hillsides have been terraced and deep plowing is now a common practice, while about half of the cultivated area has been subjected to other modern methods. Hundreds of acres once hard and bare in the winter months are now verdant with oats, clover, and other winter cover crops. The dust mulch is much more commonly and more scientifically used than formerly, though it has always been necessary to cultivate corn and cotton quite vigorously until near the middle of July for the double purpose of keeping down the grass and conserving moisture in the soil for the later use of crops.

About October 1 plowing is commenced. Those who wish to put in winter cover crops push the work rapidly. Others plow intermittently all fall and winter. As a result, a large percentage of the land of the Savannah River watershed is in ideal condition to receive the rainfall of the storage period, which embraces the months of January, February, March, and April.

During March and early in April the clods not previously harrowed for winter crops are broken up and the planting of cotton and corn progresses. For about three months, usually from the middle of April to the middle of July, the ground is thoroughly hoed or cultivated after every rain, unless the precipitation is so heavy and frequent as to prevent the fields being entered. This is a most important period in its bearing upon the conservation of moisture, for when the rainfall is not so heavy as to either maintain or augment the ground-water supply in spite of evaporation the widespread dust mulch prevents evaporation and saves the moisture in the soil.

In "Dry Farming" Widtsoe quotes a number of reports of experiments which show that on the average the evaporation from soil on which there is a well-prepared dust mulch is about 60 per cent less than from compact bare soil.

To show the difference between evaporation on cultivated and noncultivated land on which crops are growing, the following table is copied from Utah Agricultural College Bulletin No. 115, "The Movement of Water in Irrigated Soils," by W. W. McLaughlin and J. A. Widtsoe.

TABLE I.—*Effect of cultivation on the rate of loss of soil moisture.*

[Year 1902. To a depth of 8 feet. Crops growing vigorously.]

| Length of period (days after irrigation). | Average per cent of water at beginning. | Pounds of water lost per square foot. | Soil treatment. |
|---|---|---|---|
| *Days.* | *Per cent.* | *Lbs.* | |
| 31 | 17.19 | 36.28 | No cultivation. |
| 31 | 17.48 | 30.99 | Cultivated weekly. |
| | | 5.29 | |
| 20 | 16.67 | 22.37 | No cultivation. |
| 20 | 14.78 | 16.84 | Cultivated weekly. |
| | | 5.53 | |
| 20 | 16.95 | 15.87 | No cultivation. |
| 20 | 17.59 | 12.38 | Cultivated weekly. |
| | | 3.49 | |

From these figures the difference in the amount of water evaporated from thoroughly cultivated land and from ordinary agricultural land, with crops growing on both, may readily amount to 1 inch in a month. If it be assumed that one-half of the Savannah watershed is thoroughly tilled from the middle of April to the middle of July and the other half in an ordinary state of cultivation, with crops growing (though only about 20 per cent is actually in such condition and the remaining 30 per cent is largely woodland), the saving in three months for the entire shed would be 1½ inches. This, if devoted in its entirety to river flow, would maintain a stage of over 5 feet at Augusta for three months, or it would represent the difference between a 5.5-foot stage and an 8-foot stage for three months though, of course, not nearly all the water saved reaches the streams. This is merely by way of illustration, some knowledge of the factors affecting the soil's content of moisture being helpful to the river forecaster.

Agricultural development in the Savannah Valley may be safely presumed to have closely accorded with that of other portions of the Piedmont region. It will be assumed therefore, that 25 per cent of the catchment area remained covered with trees in 1909, as indicated by Mr. W. M. Moore in his report on forestry in the Piedmont section of South Carolina. Allowing 10 per cent of the area for roads and other bare ground, the remaining 65 per cent will be considered as agricultural land, cultivated for the most part though partly in pasture.

The decrease in forested area may for all practical purposes be assumed to have been proportional to the increase in agricultural lands. It being a known fact that acreage in cotton is an accurate index to agricultural activity in this section and the statistics for this crop being the only figures available for a long period of years, computations of areas have been based thereon. The following Table II is the result.

TABLE II.—*Percentage of woodland, agricultural land, and bare land in the Savannah River watershed above Augusta.*

| Year. | Woodland. | Agricultural land. | Bare land. | Cotton, Georgia and South Carolina. |
|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Acres.* |
| 1859 | 70 | 20 | 10 | [1] 2,532,600 |
| 1869 | 74 | 16 | 10 | [2] 1,703,400 |
| 1870 | 72 | 18 | 10 | ..... |
| 1871 | 70 | 20 | 10 | ..... |
| 1872 | 68 | 22 | 10 | ..... |
| 1873 | 66 | 24 | 10 | ..... |
| 1874 | 64 | 26 | 10 | [3] 2,850,000 |
| 1875 | 62 | 28 | 10 | ..... |
| 1876 | 60 | 30 | 10 | ..... |
| 1877 | 58 | 32 | 10 | ..... |
| 1878 | 56 | 34 | 10 | ..... |
| 1879 | 54 | 36 | 10 | 3,981,400 |
| 1880 | 53 | 37 | 10 | ..... |
| 1881 | 52 | 38 | 10 | ..... |
| 1882 | 51 | 39 | 10 | ..... |
| 1883 | 50 | 40 | 10 | ..... |
| 1884 | 48 | 42 | 10 | 4,675,000 |
| 1885 | 47 | 43 | 10 | ..... |
| 1886 | 46 | 44 | 10 | ..... |
| 1887 | 44 | 46 | 10 | ..... |
| 1888 | 43 | 47 | 10 | ..... |
| 1889 | 41 | 49 | 10 | 5,332,500 |
| 1890 | 41 | 49 | 10 | ..... |
| 1891 | 40 | 50 | 10 | ..... |
| 1892 | 39 | 51 | 10 | ..... |
| 1893 | 39 | 51 | 10 | 4,905,000 |
| 1894 | 38 | 52 | 10 | 5,771,400 |
| 1895 | 38 | 52 | 10 | 4,884,000 |
| 1896 | 38 | 52 | 10 | 5,482,000 |
| 1897 | 38 | 52 | 10 | 5,613,000 |
| 1898 | 37 | 53 | 10 | 5,888,000 |
| 1899 | 37 | 53 | 10 | 5,588,000 |
| 1900 | 36 | 54 | 10 | 5,978,000 |
| 1901 | 33 | 57 | 10 | 6,255,000 |
| 1902 | 33 | 57 | 10 | 6,069,000 |
| 1903 | 32 | 58 | 10 | 6,367,000 |
| 1904 | 29 | 61 | 10 | 6,759,000 |
| 1905 | 29 | 61 | 10 | 5,901,000 |
| 1906 | 27 | 63 | 10 | 6,989,000 |
| 1907 | 25 | 65 | 10 | 7,200,000 |
| 1908 | 23 | 67 | 10 | 7,393,000 |
| 1909 | 23 | 67 | 10 | 7,166,000 |
| 1910 | 21 | 69 | 10 | 7,596,000 |
| 1911 | 19 | 71 | 10 | 7,824,000 |
| 1912 | 19 | 71 | 10 | 7,625,000 |

[1] Estimated from production, allowing 3 acres for each bale of 500 pounds.
[2] Estimated from production, allowing yield per acre that obtained in 1879.
[3] Interpolated.

During the Civil War much land previously cultivated was abandoned. Complete recovery and return to the acreage of 1859 did not occur until 1870 or a little later, so that the prolific, quick-growing shortleaf pine had had ample time to restore the abandoned land to forest conditions, the pine thickets being equivalent to primal conditions in their effect upon run-off. The percentages given in the above table may, therefore, be accepted as accurate within a narrow margin of error.

Since 1870 the ratio between woodland and agricultural land has reversed. In 1870 forests covered approximately 70 per cent of the area of the Piedmont section of the watershed and agricultural land about 20 per cent. The alpine section is unnecessary to consider. At the present time woodland occupies only 20 per cent of its area, mostly in farm woodlots, while agricultural land occupies about 70 per cent.

### SURFACE RUN-OFF—HIGH WATER STAGES.

Importance attaches to the 20-foot stage of the Savannah River at Augusta by reason of the fact that when it is reached some of the river farms below Augusta are inundated. It is also of interest to lumbermen, since it enables them to float logs out of the swamps, and to contractors working on Government and municipal developments along the river front and below the city, as well as to river transportation companies. Stages above 20 feet are of increasing importance as the depth increases, though water does not enter Augusta until the 32-foot stage is reached, and does not cause general concern until the 34-foot stage is attained, when a considerable area in the business section is affected. At 36 feet a wide area of the business and residence sections is covered to depths of from 1 to 3 feet.

### RELATION OF SURFACE RUN-OF TO HIGH WATER.

Primary surface run-off is that which occurs practically simultaneously with the falling of the rain by which it is caused.

Secondary surface run-off may be defined as the more gradual discharge of water from thoroughly saturated surface soil or forest mulch and humus. It is quite pronounced under forest conditions, and is common from cultivated areas after slow, steady rainfall.

Chittenden and other writers have pointed out that delayed run-off from forests may considerably augment the volume of a freshet or flood in such a way as to counterbalance any tendency deforestation might have to occasion increases of high water in volume or frequency, the delayed flow lower down combining with the primary run-off from above. However that may be for longer rivers, in a short stream like the upper Savannah River freshets can be affected only when the delayed run-off from one rain that has supersaturated the surface soil combines with the primary run-off from another rain falling not more than two or three days later. Sequence of precipitation calculated to produce such an effect is found by detailed study of the daily values for the upper Savannah River for 20 years, to be unusual. It follows that for purposes of general discussion of the frequency and volume of high water at Augusta delayed run-off may be ignored, its only office being to maintain a somewhat more active flow after some freshets than would otherwise exist.

The number of days with the Savannah River at or above the 20-foot stage at Augusta has increased with the

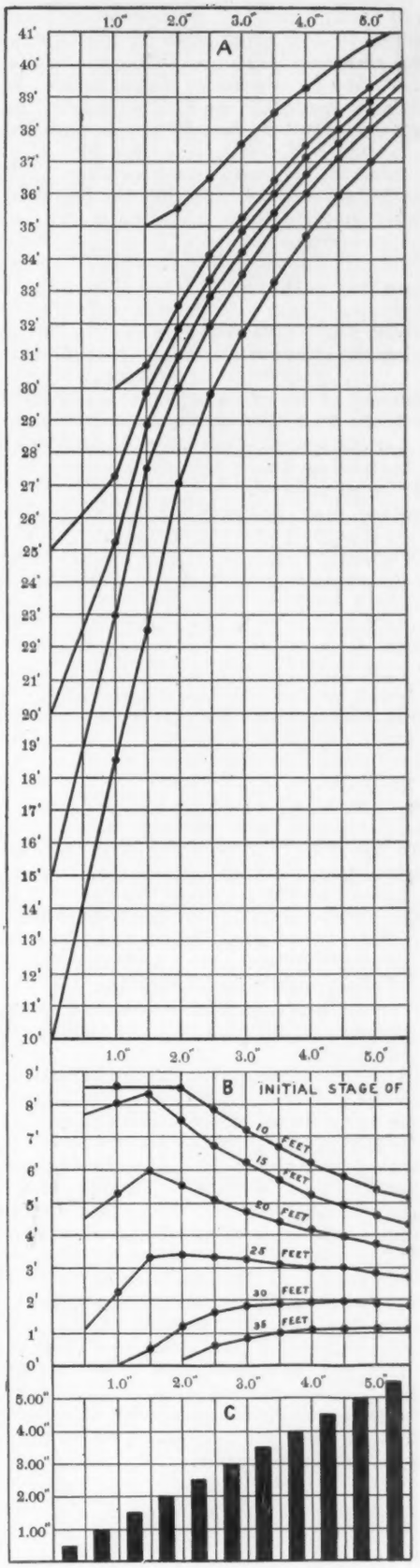


FIG. 2.—River forecast scheme. Diagram No. I. Relation of 24-hour rainfall over the Savannah River watershed to river stages at Augusta, Ga. A. Initial and resulting stages. B. Rise per inch of rain. C. Rainfall in inches.

expansion of agricultural and contraction of forest area. It may be well to now attempt to fix the extent of this increase and ascertain its cause. This can be done with sufficient accuracy by the use of simple ratios.

During the 10 years 1877 to 1887 (1878 being omitted) the average rainfall for the storage period (January, February, March, and April) was 20.9 inches, and the average number of days with the river stage at Augusta at or above 20 feet was 8.4. During the 10 years 1902–1911 the average rainfall for the same months was 16.1 inches, and the average number of days of 20 feet or over, was 10. Although the rainfall in the first 10 years was 30 per cent more than in the last 10 years, the number of days in the first group of years with the river depth at Augusta 20 feet or over, was 20 per cent less than in the last.

In studying the above ratios it is important to remember that—

1. The amount of rise to reach 20 feet is not considered.
2. They figure from zero as the basis of computation of rainfall percentage, whereas only the amount of rain exceeding that below which the 20-foot stage is impossible should be considered.

The question may properly be asked whether the demonstrated greater frequency of river depths of 20 feet and over necessarily indicates a more active surface run-off. Since the average river stage has increased in depth approximately 3 feet, less rainfall is now required than formerly to occasion a rise to any high-water stage on the Augusta gage.

Starting from initial stages below 16 feet, the normal amount of rise in the Savannah River at Augusta for each inch of rain in 24 hours over the catchment area with the ground in moist condition is 8.5 feet. This remains true until rain has brought the river to its 29-foot stage. Any surplus of water above that necessary to cause a 29-foot stage has a value of about 3 feet for each inch of rain. The 3 feet difference in gage readings added to the initial stages of the 1877–1887 group of years increases by 3 feet the original gage readings up to the 26-foot stage; by more than 2 feet the 27-foot stage; by nearly 2 feet the 28-foot stage; and by about 1 foot all other gage readings up to about the 34-foot stage, where the effect becomes negligible. Nearly all rises now, and formerly a greater proportion of them, originated below the 16-foot stage. For the purpose in hand, the few rises starting from stages above 16 feet may be included without serious effect on the result.

If, instead of figuring from zero as the basis of computation of rainfall percentages, we take into account only rainfall above the amount below which the 20-foot stage is impossible, the following results are obtained:

At the present time about 12 inches of rain is required during the first four months of the year in order that the 20-foot stage may become possible. Snow seldom falls and never has any appreciable effect on the river's recorded stages, being followed by cold weather and slow melting.

During the 10 years 1877–1887 (1878 being omitted) there were 14.7 days, on the average, with river stages of 17 feet or over, during the first four months of the year; this would be equivalent to the number of days 20 feet or over had the initial stage been 3 feet higher, as in the 1902–1911 group of years. A comparison of these 14.7 days of 17 feet or over with the 10 days' average for stages of 20 feet or over in the 1902–1911 group of years, shows the former to have been 47 per cent greater.

Using the usual correlation formula, as used and explained by Prof. J. Warren Smith in his study of the Ohio River, it is found that there is a harmonious relation between the rainfall during January, February, March, and April and the number of days with the river above certain stages at Augusta, the probable error in each computation being negligible.

The following are the coefficients:

Comparing days 20 feet or above and rainfall: Coefficient for 1877–1887 = 0.85, with probable error $\pm 0.06$.

Comparing days 17 feet or above and rainfall: Coefficient for 1877–1887 = 0.81, with probable error $\pm 0.08$.

Comparing days 20 feet or above and rainfall: Coefficient for 1902–1911 = 0.96, with probable error $\pm 0.02$.

In 1877–1887 the rainfall actively applied to producing days with stages of 17 feet or over was: $20.9 - 12.0 = 8.9$ inches.

In 1902–1911 the rainfall actively applied to producing days with stages of 20 feet or over was $16.1 - 12.0 = 4.1$ inches.

The amount of rainfall effective in producing comparable stages was, therefore, 117 per cent greater in 1877–1887 than in 1902–1911; the number of days with stages of 17 feet and over in the first group of years was only 47 per cent greater than the number of days with stages of 20 feet and over in the last group. This shows an increase in surface run-off to which it is desirable to assign an approximately definite value.

Since the mean of the correlation coefficients of the two 10-year groups is about 0.90, and the average number of days with 20 feet or over in the 1902–1911 group is 10, the number of days with stages of 20 feet or over to be expected from 8.9 inches of effective rainfall during the first four months of the year under present run-off conditions is: $0.90 \times 2.17 \times 10.0 = 19.5$ days.

This is equivalent to 19.5 days with stages of 17 feet and over under original ground-water conditions and new surface run-off conditions and the following computation is in order, 20.9 inches of rainfall being assumed:

Let

$a$ = Original average stream flow, days of 17 feet or over.

$b$ = New surface run-off, days of 17 feet or over.

$c$ = Forest surface run-off, days of 17 feet or over.

Then $a + b = 19.5$ days.

$a + c = 14.7$ days.

and $b - c = 4.8$ days = difference in effect of old and new surface run-off.

This corresponds to 4.8 days of 20 feet or over now and since the average number of days of 20 feet or over in 1877–1887 was 8.4 and the same rainfall now should cause 19.5 days, the number of days increase due to increase in depth of average stream flow may be ascertained as follows:

$19.5 - 8.4 = 11.1$ days, increase for 20.9 inches of rain.

Of these 11.1 days, 4.8 are due to greater surface flow.

Therefore, $11.1 - 4.8 = 6.3$ days of the increase are due to an increase of 3 feet in depth of average stream flow.

The above discussion being somewhat empirical, it will be well to inspect the records to determine the accuracy of the conclusion that 21 inches of rain in the first four months of the year will ordinarily cause the river at Augusta to be 20 feet deep or more during 20 days of that time.

| Year. | Rainfall, January-April. | Days of 20 feet or over. |
|---|---|---|
| 1903 | 24.6 | 23 |
| 1906 | 17.8 | 14 |
| 1908 | 19.8 | 24 |
| 1909 | 18.2 | 12 |
| 1912 | 25.2 | 25 |
| Means | 21.1 | 20 |

The criticism may be raised that the argument presented deals indiscriminately with all stages above 20 feet without regard to the volume of the freshets. This, however, is only an apparent, not a real, objection. The number of days of 20 feet or over is dependent on the effective amount of rainfall. If the precipitation be of short duration but great intensity, it occasions a high stage that keeps the river above 20 feet for several days. If the rainfall be of the same amount but lower intensity, extending over two or three days instead of one, the result in terms of days 20 feet or over is practically the same, though the crest of the flood is somewhat lower. The formula used does include stages well above 20 feet and tends to indicate for them the same facts as are proven for the entire class of stages 20 feet or over.

The rise of March, 1912, which reached 36.8 feet on the gage, undoubtedly owed much of its extraordinary height to the absence of the forests. The ground was uncut by the plow and was thoroughly packed and saturated by the incessant abnormal rainfall of several months that had prevented field work of any kind. The hillsides, therefore, presented hard, smooth inclines, from which the flow was so rapid that the water piled up in the river and had no opportunity to level out before it reached Augusta. The obstructions presented by a forest or by cultivated fields would have given a much better regulated flow.

Aside from extremely rare occurrences such as that of 1912, however, the increase in surface run-off of the present time over that of earlier years is largely and probably entirely attributable to the fact that under forest conditions more rain was required to bring the surface run-off to its maximum volume, and not to greater activity of the run-off when once established. If, therefore, as is occasionally the case, at the beginning of a period of heavy rainfall a considerable quantity of water must be retained to wet the soil, then the ultimate river stages must necessarily be affected according to the amount of water thus withheld from the main streams. The greater surface run-off of the present day and the greater depth of normal flow combined, can readily be shown to have an important effect even on very high river stages when the capacity of the surface soil for moisture has not been previously satisfied and the rainfall producing the high stage is of only one or two days' duration.

The 24-hour rainfall equivalent of the 3-foot difference in normal stage is 0.35 inch.

The 3-foot difference in normal stage caused an increase in the number of days when the river at Augusta was 20 feet or over, of 6.3 days.

Increased surface run-off caused a difference in the number of days when the river was 20 feet or over at Augusta, of 4.8 days.

Now 6.3 : 4.8 :: 0.35 : 0.27; consequently 0.27 inch is the rainfall equivalent for increased surface run-off.

This makes the increased tendency for high stages, with the ground in ordinary condition, correspond to 0.62 inch of rain in 24 hours, and is capable of increasing stages as follows:

The 32-foot stage to 34 feet.
The 33-foot stage to 35 feet.
The 34-foot stage to 35.5 feet.
The 35-foot stage to 36.4 feet.
The 36-foot stage to 37.3 feet.
The 37-foot stage to 38.1 feet.

While it may be stated as a general proposition that the great freshets come only after the soil has been thoroughly saturated, and that the state of soil saturation is usually the result of previous rains, the importance of the class of exceptions above outlined should not be underestimated in considering a stream as flashy as is the Savannah River.

The greatest of all freshets, that of 1796, when, according to reliable estimates, the Savannah River at Augusta carried 40 feet of water, the Harrison freshet of 1840 and the rise of 1852, both of these being above 37 feet, occurred while the forests remained intact. On the other hand, eight of the twelve stages of 34 feet or over during the 73 years from May, 1840, to March, 1913, occurred in the last 26 years and included the great freshet of 1888, 38.7 feet, and that of 1908, 38.8 feet. Three of the twelve have been recorded in the past five years.

TABLE III.—*River stages of 34 feet and over in the Savannah River at Augusta, Ga.*

| Year. | Stage. | Date. |
|---|---|---|
| | *Feet.* | |
| 1796 | [1] 40 | February. |
| 1840 | 37.8 | May 28. |
| 1852 | 37.4 | Aug. 29. |
| 1864 | 34.9 | Jan. 1. |
| 1865 | 36.9 | Jan. 11. |
| 1887 | 34.6 | July 31. |
| 1887 | 34.3 | Aug. 10. |
| 1888 | 38.7 | Sept. 11. |
| 1891 | 35.5 | Mar. 9. |
| 1902 | 34.6 | Mar. 1. |
| 1908 | 38.8 | Aug. 27. |
| 1912 | 36.8 | Mar. 16. |
| 1913 | 35.1 | Mar. 16. |

[1] Estimated.

TABLE IV.—*Savannah River stages of 25 feet and over at Augusta, Ga., September, 1875, to December, 1912.*

| Year. | Jan. | | Feb. | | Mar. | | Apr. | | May. | | June. | | July. | | Aug. | | Sept. | | Oct. | | Nov. | | Dec. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. | Stage | Date. |
| | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* | |
| 1875[1] | | | | | | | | | | | | | | | | | | | | | | | 27.4 | 30 |
| 1876 | | | | | | | 25.6 | 12 | | | | | | | | | | | | | | | | |
| 1877 | | | | | | | 29.8 | 14 | | | | | | | | | | | | | | | | |
| 1878 | | | | | | | | | | | | | | | | | | | | | | | | |
| 1879 | | | | | | | | | | | | | | | | | | | | | | | 30.1 | 16 |
| 1880 | | | | | 28.4 | 17 | | | | | | | | | | | | | | | | | | |
| 1881 | 30.5 | 21 | 29.5 | 11 | 32.2 | 18 | | | | | | | | | | | | | | | | | | |
| | | | 28.4 | 13 | 30.7 | 20 | | | | | | | | | | | | | | | | | | |
| 1882 | | | 26.8 | 5 | | | | | | | | | | | | | 29.4 | 12 | | | | | | |
| | | | 27.0 | 10 | | | | | | | | | | | | | | | | | | | | |
| 1883 | 30.8 | 22 | | | | | 27.5 | 11 | | | | | | | | | | | | | | | | |
| | | | | | | | 25.5 | 24 | | | | | | | | | | | | | | | | |
| 1884 | | | | | 26.2 | 14 | 28.0 | 16 | | | 25.8 | 26 | | | | | | | | | | | | |
| | | | | | 26.3 | 21 | | | | | | | | | | | | | | | | | | |
| 1885 | 27.6 | 26 | | | | | | | | | | | | | | | | | | | | | | |
| 1886 | 30.5 | 5 | | | | | 32.2 | 1 | 32.5 | 21 | | | 27.9 | 2 | | | | | | | | | | |
| 1887 | | | | | | | | | | | | | 34.6 | 31 | 33.3 | 4 | | | | | | | | |
| | | | | | | | | | | | | | | | 34.3 | 10 | | | | | | | | |
| 1888 | 25.6 | 3 | 29.2 | 26 | 32.8 | 30 | | | | | | | | | | | 38.7 | 11 | | | 25.8 | 16 | | |
| 1889 | 25.1 | 28 | 33.3 | 18 | | | | | | | | | | | | | | | | | | | | |
| 1890 | | | | | | | | | | | | | | | | | | | 28.5 | 1 | | | | |
| | | | | | | | | | | | | | | | | | | | 27.9 | 24 | | | | |
| 1891 | | | 27.6 | 9 | 35.5 | 10 | | | | | | | | | 25.4 | 28 | | | | | | | | |
| | | | | | 31.3 | 13 | | | | | | | | | | | | | | | | | | |
| | | | | | 29.1 | 28 | | | | | | | | | | | | | | | | | | |
| 1892 | 29.4 | 15 | 26.4 | 22 | 27.6 | 27 | 25.6 | 9 | | | | | | | | | | | | | | | | |
| | 32.8 | 20 | | | | | | | | | | | | | | | | | | | | | | |
| 1893 | | | 25.4 | 14 | | | | | | | | | | | | | | | | | | | | |
| 1894 | | | | | | | | | | | | | | | | | | | 27.7 | 10 | | | 26.2 | 13 |
| 1895 | 30.5 | 11 | | | 28.5 | 16 | | | | | | | | | 30.5 | 23 | | | | | | | | |
| 1896 | | | | | | | | | | | | | 30.5 | 9 | | | | | | | | | | |
| 1897 | | | 27.5 | 7 | 25.6 | 15 | 29.3 | 6 | | | | | | | | | | | | | | | | |
| 1898 | | | 25.0 | 17 | | | | | | | | | | | | | 28.5 | 2 | | | | | | |
| 1899 | | | 31.0 | 8 | 28.8 | 1 | | | | | | | | | | | | | | | | | | |
| | | | 30.2 | 28 | 25.5 | 17 | | | | | | | | | | | | | | | | | | |
| 1900 | | | 32.7 | 14 | | | 25.2 | 19 | | | 29.4 | 25 | | | | | | | | | | | | |
| | | | | | | | 28.0 | 22 | | | | | | | | | | | | | | | | |
| 1901 | | | 27.3 | 5 | 29.8 | 27 | 31.8 | 4 | 27.7 | 23 | 27.2 | 15 | | | 29.1 | 29 | 31.6 | 19 | | | | | 31.0 | 31 |
| 1902 | | | 32.6 | 3 | 34.6 | 1 | | | | | | | | | | | | | | | | | | |
| | | | | | 28.5 | 17 | | | | | | | | | | | | | | | | | | |
| | | | 33.2 | 9 | 27.0 | 1 | | | | | | | | | | | | | | | | | | |
| 1903 | | | 28.8 | 12 | 28.4 | 30 | | | | | 27.3 | 8 | | | | | | | | | | | | |
| | | | 29.9 | 18 | 30.0 | 25 | | | | | | | | | | | | | | | | | | |
| | | | | | 27.6 | 31 | | | | | | | | | | | | | | | | | | |
| 1904 | | | | | | | | | | | | | | | 25.5 | 10 | | | | | | | | |
| 1905 | | | 25.8 | 14 | | | | | | | | | | | | | | | | | | | 28.3 | 22 |
| 1906 | 29.6 | 5 | | | 25.0 | 16 | | | | | | | | | | | | | | | | | | |
| | 29.1 | 24 | | | 28.6 | 21 | | | | | | | | | | | | | | | | | | |
| 1907 | | | | | | | | | | | | | | | | | | | | | | | 28.8 | 24 |
| | | | | | | | | | | | | | | | | | | | | | | | 28.0 | 31 |
| 1908 | 27.4 | 13 | 27.6 | 2 | | | | | | | | | | | 38.8 | 27 | | | | | | | 26.5 | 23 |
| | | | 25.8 | 12 | 29.8 | 25 | | | | | | | | | | | | | | | | | | |
| | | | 26.0 | 17 | | | | | | | | | | | | | | | | | | | | |
| 1909 | | | 28.1 | 11 | 26.7 | 11 | | | 25.9 | 2 | 28.7 | 5 | | | | | | | | | | | | |
| | | | 26.4 | 24 | 28.0 | 15 | | | | | | | | | | | | | | | | | | |
| 1910 | | | | | 26.4 | 2 | | | | | | | | | | | | | | | | | | |
| 1911 | | | | | | | | | | | | | | | | | | | | | | | 31.5 | 24 |
| 1912 | | | 29.9 | 16 | 25.8 | 7 | | | | | | | | | | | | | | | 27.4 | 7 | | |
| | | | 24.9 | 27 | 36.8 | 16 | 26.5 | 23 | | | 25.3 | 16 | | | | | | | | | | | | |
| | | | | | 25.8 | 30 | | | | | | | | | | | | | | | | | | |

[1] No record until September, 1875.

TABLE V.—*Number of days the Savannah River was 20 feet or over at Augusta, Ga.*

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1875 | .... | .... | .... | .... | .... | .... | .... | .... | 0 | 0 | 0 | 2 | .... |
| 1876 | 1 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 1877 | 0 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 7 |
| 1878 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 1879 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 3 | 6 |
| 1880 | 0 | 0 | 8 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 10 |
| 1881 | 4 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 17 |
| 1882 | 0 | 6 | 4 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 14 |
| 1883 | 9 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| 1884 | 1 | 2 | 13 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 23 |
| 1885 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 8 |
| 1886 | 3 | 0 | 2 | 3 | 4 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 14 |
| 1887 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 10 | 0 | 0 | 0 | 0 | 12 |
| 1888 | 2 | 3 | 6 | 1 | 1 | 0 | 0 | 0 | 10 | 1 | 4 | 0 | 28 |
| 1889 | 5 | 8 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 15 |
| 1890 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 8 |
| 1891 | 2 | 10 | 10 | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 28 |
| 1892 | 10 | 2 | 2 | 3 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 21 |
| 1893 | 0 | 5 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 9 |
| 1894 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 2 | 0 | 2 | 11 |
| 1895 | 5 | 0 | 5 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 13 |
| 1896 | 1 | 4 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 1 | 0 | 11 |
| 1897 | 1 | 6 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| 1898 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 1 | 6 |
| 1899 | 1 | 8 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| 1900 | 0 | 5 | 2 | 6 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 18 |
| 1901 | 2 | 3 | 3 | 5 | 3 | 3 | 0 | 8 | 5 | 0 | 0 | 3 | 33 |
| 1902 | 1 | 4 | 9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 16 |
| 1903 | 0 | 11 | 9 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| 1904 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| 1905 | 0 | 5 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 11 |
| 1906 | 9 | 0 | 5 | 0 | 0 | 5 | 2 | 0 | 2 | 2 | 0 | 0 | 25 |
| 1907 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 11 |
| 1908 | 7 | 9 | 4 | 4 | 0 | 0 | 0 | 5 | 1 | 0 | 0 | 2 | 32 |
| 1909 | 1 | 5 | 6 | 0 | 3 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 20 |
| 1910 | 1 | 2 | 2 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 8 |
| 1911 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 5 |
| 1912 | 1 | 9 | 9 | 6 | 1 | 5 | 1 | 0 | 1 | 1 | 2 | 0 | 36 |

## FORECASTING HIGH WATER AT AUGUSTA, GA.

When in 1888 a great freshet broke upon Augusta the muddy waters of the restless Savannah flowed through the streets of the city for the first time in nearly a quarter of a century and were of greater depth, velocity, and destructive force than at any time since the flood of 1796. Fear of the water had disappeared, and its full possibilities as a destroyer of life and property had become a mere tradition dimmed by the passing of many years.

The freshet of 1888, however, impressed upon the public mind a conviction of the necessity for some means of protection, and that there might be opportunity to safeguard life and movable property the Augusta district of the River and Flood Service of the Weather Bureau was organized in 1892 to give warning of the approach of dangerously high water.

Since 1892 there has accumulated a valuable series of daily rainfall observations for the Savannah River watershed above Augusta, and an earnest effort has been made to obtain from the data a scheme for the forecasting of river stages at Augusta as accurate and complete as can be devised. Since the rises are flashy, sometimes being very sudden, river-gage reading at points above are usually of little avail, and estimates must be based upon the relation between the average rainfall over the catchment basin and the stages normally resulting therefrom under the existing conditions. Such a scheme can not be expected to give absolutely accurate results in every instance, but tests have shown a degree of accuracy that meets every practical requirement.

Predictions of high-water stages have been made for Augusta for a number of years, and frequently with considerable accuracy and success, but in some instances the warnings preceded the flood crests by so few hours that their usefulness was greatly impaired. This feature was one of the first to receive my attention three years ago in my effort to make the work more effective, and it can be confidently stated that the possibility of the development of dangerous river conditions without ample and timely warning has been fully eliminated.

With 9 stations outside of Augusta telegraphing each inch of rain as it falls during the day, each half inch or more for the 24 hours ending at 8 a. m., and special reports whenever requested, the river forecaster is at all times in possession of the detailed information necessary for the proper performance of his duties. Additional security from surprise is afforded by placing nearly all of the instruments in the hands of telegraph operators, who can telegraph reports even at night if an emergency should require it.

Nearly all of the river forecasts are for the information of farmers, lumbermen, steamboat companies, and engineers and contractors engaged on Government or municipal developments along the river. Only on rare occasions does it become necessary to give warnings of stages dangerous to Augusta itself, but occasionally the river rises high enough to cause apprehension. Whether the desire for information is inspired by a prediction of actual danger or merely by a general fear of danger, every effort is made to secure and disseminate the most reliable information obtainable. Predictions are made for all stages above 18 feet.

Excellent opportunity during the past two years to observe the river under nearly all possible conditions has supplied much experience that was needed to point out some facts not made sufficiently clear by the abstract study of the records. This experience has indeed been so useful that it seems warrantable to complete the work of putting the forecast scheme in permanent form.

In the South, where snow and ice are almost unknown and never accumulate to any extent, the forecasting of high river stages from reports of precipitation is comparatively simple. The question in each instance resolves itself into the determination of the probable effect of the average rainfall over the watershed as indicated by telegraphic reports from selected stations.

The chief difficulty arises from varying absorption by the ground, according to its degree of dryness and the rate of rainfall. A very dry or only slightly moist soil often absorbs so much rain, even when the amount is considerable, that the immediate effect upon the river is negligible. General heavy downpours on dry ground might conceivably result in a rapid run-off of water and a consequent material rise in the river, but rains of this intensity usually come in the summertime and are characteristically so local that their simultaneous occurrence over all or a large portion of the catchment area, which embraces 7,294 square miles, is a very remote possibility. Freshets of magnitude take place in the Savannah River at Augusta only after the ground in the upper reaches of the stream has become saturated.

Water from the more distant portions of the watershed also complicates the problem, for when the rainfall covers two or more consecutive 24-hour periods on the second and subsequent days an allowance must be added for the volume from the distant streams. In summer another uncertainty is introduced by the erratic distribution of the showers of that season.

### DEVELOPMENT OF THE RIVER FORECAST SCHEME.

It is intended to discuss first the effect upon the river at Augusta of rains falling within a 24-hour period, then the effect of rains extending into 48-hour and longer periods. This discussion is based for the most part on

records for the 24 hours ending at 8 a. m., but in some cases when it was evident that the actual 24-hour rainfall covered the observation hour the records for two dates were combined.

It appears from the figures about to be set forth and the charts accompanying this paper, that neither the exact time of occurrence of rain at the various stations, nor the time and duration of the heaviest downpours, nor the distribution of the amounts at the various stations, is of great importance under ordinary circumstances in influencing the height ultimately reached by the water. All of these questions may in special instances become important, however, and it is on this account that observers are required to immediately report all heavy rainfall during the day.

Flood crests usually reach Augusta in from 18 to 30 hours after the receipt of the rainfall telegrams. The distribution of amounts has much to do with the rate of rise and the time of arrival of the crest of the rise, though, as has been intimated, it has little effect on the magnitude of the ultimate stage.

The averages given in the tables are based chiefly on rainfall measurements at seven points in the Savannah River watershed above Augusta, but during the first 10 years there were only six stations in operation much of the time. The seven stations for which most of the averages were computed are Augusta, Ga., Washington, Ga., Greenwood, S. C., Calhoun Falls, S. C., Carlton, Ga., Anderson, S. C., and Toccoa, Ga.

The consistency in the relation between the rainfall averages and the river stages in all but a few instances, demonstrates that the six or seven reports used give true averages for the watershed. To provide against the repetition of the few unreliable averages, however, additional stations were established in July, 1912, at Camak, Ga., Edgefield, S. C., and Gillsville, Ga. A balanced horizontal distribution of rainfall stations has always been maintained, with a somewhat greater number on the Georgia side on account of the greater number and greater importance of the tributaries there. River gage readings are reported from Carlton, Ga., on the Broad River, and Calnoun Falls, S. C., on the Savannah River.

*Tables of importance in forecasting.*

The natural supposition is that the higher the water in the river becomes the less will be the effect of a given portion of the total amount of rainfall in producing any further increase in depth. Beyond a certain river stage, which may be conservatively placed at 29 feet at Augusta, this is true of the Savannah River. When the soil is moist at the outset the normal rise from stages under 16 feet, remains near 8.5 feet for each inch of average rainfall over the watershed in 24 hours until the 29-foot stage is reached. In a few instances the rise for each inch of rain has exceeded 9 feet, but 8.5 feet gives an excellent working basis for forecasting purposes.

A partial explanation of this persistency of rise is, that the ground absorption reduces the rise at lower stages to such an extent as to counterbalance much of the retarding effect of the increasing width of the stream and the accelerated velocity of the current at higher stages. Additional explanation is found in the fact that the percentage of run-off from the faster rate of fall of larger amounts of rain is enough greater than the percentage of run-off from the slower rate of fall of the smaller amounts of rain, to materially assist in giving, for the larger amounts, the same average rise in feet per inch of rain, with high resultant stages, as results from smaller amounts with lower stages.

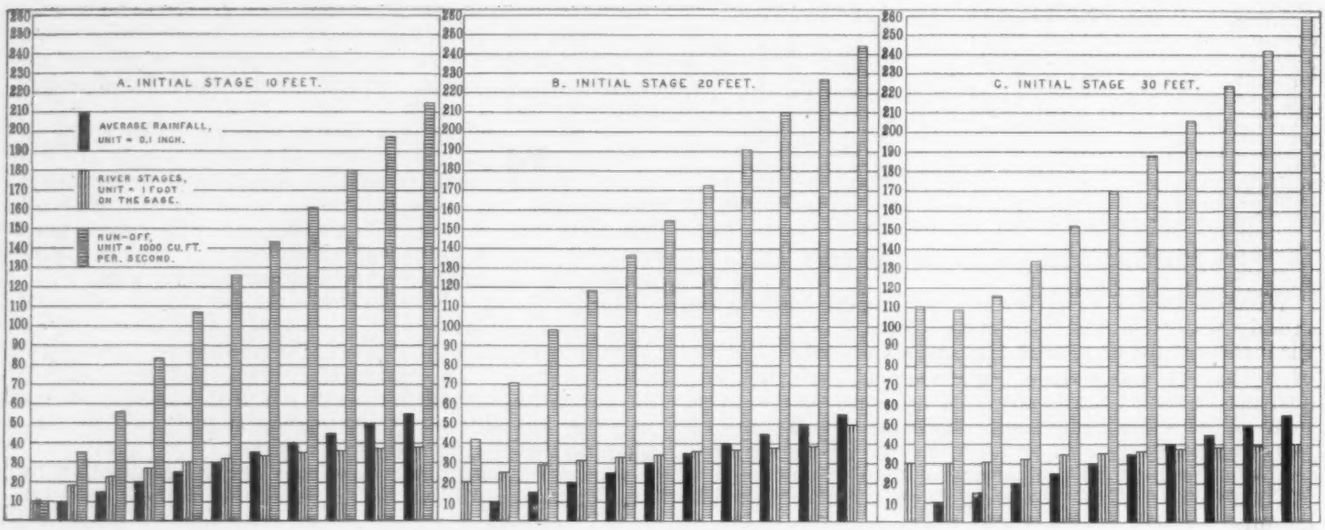
A. INITIAL STAGE 10 FEET.
B. INITIAL STAGE 20 FEET.
C. INITIAL STAGE 30 FEET.
AVERAGE RAINFALL, UNIT = 0.1 INCH.
RIVER STAGES, UNIT = 1 FOOT ON THE GAGE.
RUN-OFF, UNIT = 1000 CU. FT. PER. SECOND.

FIG. 3.—River forecast scheme. Diagram No. II. Relation of 24-hour rainfall over the Savannah River watershed to river stages, and run-off in cubic feet per second at Augusta, Ga. A. Initial stage 10 feet. B. Initial stage 20 feet. C. Initial stage 30 feet.

The following is the key to the Savannah River forecast scheme. In Table VI are given the results of a few rainfalls averaging less than an inch in 24 hours for the catchment area, the mean rise for such rains on moist soil being found to be 8.4 feet per inch of precipitation. In Tables VII and VIII, which contain all records from January 1, 1892, through April, 1912, the mean rise per inch of rain is found to be 8.7 feet for 24-hour rains of 1 to 1.50 inches, and 8.5 feet for rains of 1.51 to 2.50 inches. Table IX gives the results of heavier 24-hour rains on stages of 16 feet or less and indicates a value of about 3 feet for each inch of rain in excess of the amount

required to produce the 29-foot stage. All but one of the rainfall averages in this table are in excess of 3 inches, and the results in all but one instance are close to estimates based on the forecasting table. (Table XI.) The excessive rise of March 15, 1912, when the river reached 36.8 feet on the gage as against a maximum estimate of 35.1, resulted from the soil being entirely uncultivated. Persistent rains had prevented the usual winter plowing and left the hillsides completely saturated as well as hard and bare.

TABLE VI.—*Effect of 24-hour rains of less than 1 inch over the Savannah River watershed, on river stages below 16 feet at Augusta, Ga.*

[Estimated rise of 8.5 feet per average inch of rainfall.]

| Date. | Average rainfall. | Initial stage. | Rise to highest stage. | Rise per inch of rain. | Estimated stage. | Highest stage. |
|---|---|---|---|---|---|---|
| | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Dec. 20, 1892 | 0.80 | 9.1 | 6.4 | 8.0 | 15.9 | 15.5 |
| Mar. 2, 1895 | .87 | 8.9 | 8.8 | 9.4 | 16.3 | 17.2 |
| Mar. 8, 1895 | .96 | 10.5 | 7.4 | 7.7 | 18.7 | 17.9 |
| Apr. 22, 1900 | .80 | 10.3 | 5.2 | 6.5 | 17.1 | 15.5 |
| Nov. 26, 1900 | .90 | 7.2 | 7.0 | 6.5 | 14.8 | 14.2 |
| Jan. 11, 1903 | .61 | 9.0 | 5.2 | 8.5 | 14.2 | 14.2 |
| Feb. 9, 1905 | .95 | 8.5 | 9.3 | 9.8 | 16.6 | 17.8 |
| Jan. 12, 1905 | .80 | 10.5 | 5.5 | 6.9 | 17.3 | 16.0 |
| Sept. 12, 1905 | [1].88 | 9.1 | 7.9 | 9.0 | 16.4 | 17.0 |
| Mar. 2, 1907 | .60 | 12.0 | 5.0 | 8.3 | 17.1 | 17.0 |
| Mar. 7, 1909 | .41 | 10.8 | 4.0 | 9.8 | 14.3 | 14.8 |
| Mar. 25, 1909 | .59 | 12.8 | 5.1 | 8.7 | 17.8 | 17.9 |
| June 30, 1910 | .68 | 10.3 | 5.9 | 8.7 | 16.1 | 16.2 |
| Mean | .75 | 9.8 | | 8.4 | | |

[1] Reports covered two dates, but rain fell in 24 hours.

NOTE.—The above table embraces only a few illustrative examples.

TABLE VII.—*Effect of 24-hour rains of 1 inch to 1.50 inches over the Savannah River watershed, on river stages below 16 feet at Augusta, Ga.*

[Estimated rise of 8.5 feet per average inch of rainfall.]

| Date. | Average rainfall. | Initial stage. | Rise to highest stage. | Rise per inch of rain. | Estimated stage. | Highest stage. |
|---|---|---|---|---|---|---|
| | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Sept. 22, 1892 | 1.06 | 12.3 | 8.5 | 8.0 | 21.3 | 20.8 |
| Feb. 28, 1893 | 1.24 | 8.9 | 12.1 | 9.8 | 19.4 | 21.0 |
| Apr. 17, 1895 | 1.15 | 8.8 | 10.0 | 8.7 | 18.6 | 18.8 |
| Dec. 15, 1896 | 1.30 | 7.3 | 10.3 | 7.9 | 18.3 | 17.6 |
| Jan. 21, 1897 | 1.35 | 10.2 | 11.0 | 8.0 | 21.7 | 21.2 |
| Feb. 12, 1897 | [1] 1.40 | 12.1 | 10.8 | 7.7 | 24.0 | 22.9 |
| Apr. 1, 1897 | [1] 1.22 | 9.4 | 10.2 | 8.4 | 19.8 | 19.6 |
| May 1, 1897 | 1.07 | 8.9 | 8.0 | 7.5 | 18.0 | 16.9 |
| Aug. 21, 1897 | [1] 1.12 | 12.0 | 8.4 | 7.5 | 21.5 | 20.4 |
| Mar. 1, 1900 | [2] 1.41 | 10.3 | 13.0 | 9.3 | 22.3 | 23.4 |
| June 2, 1903 | 1.34 | 10.2 | 10.4 | 7.8 | 21.6 | 20.6 |
| Mar. 7, 1904 | 1.05 | 8.1 | 9.5 | 9.0 | 17.0 | 17.6 |
| Jan. 12, 1908 | 1.50 | 13.0 | 14.4 | 9.6 | 25.7 | 27.4 |
| Apr. 27, 1908 | 1.26 | 12.3 | 11.7 | 9.3 | 23.0 | 24.0 |
| Jan. 17, 1909 | [1] 1.14 | 10.7 | 10.3 | 9.0 | 20.4 | 21.0 |
| Mar. 10, 1909 | 1.40 | 12.8 | 13.9 | 9.9 | 24.7 | 26.7 |
| Feb. 18, 1910 | 1.29 | 9.4 | 12.0 | 9.3 | 20.4 | 21.4 |
| Feb. 24, 1910 | [1] 1.02 | 15.2 | 9.1 | 8.9 | 23.9 | 24.3 |
| Jan. 3, 1911 | 1.09 | 9.0 | 9.4 | 8.6 | 18.3 | 18.4 |
| Feb. 22, 1912 | [1] 1.10 | 13.2 | 11.1 | 10.0 | 22.6 | 24.3 |
| Mar. 29, 1912 | 1.34 | 13.5 | 12.3 | 9.2 | 24.9 | 25.8 |
| Mean | 1.23 | 10.8 | | 8.7 | | |

[1] Reports covered two dates, but rain fell in 24 hours.
[2] Mean for 16 stations; 6 stations gave mean of 1.20 inches.

TABLE VIII.—*Effect of 24-hour rains of 1.51 to 2.50 inches over the Savannah River watershed, on river stages below 16 feet at Augusta, Ga.*

[Estimated rise of 8.5 feet per average inch of rainfall.]

| Date. | Average rainfall. | Initial stage. | Rise to highest stage. | Rise per inch of rain. | Estimated stage. | Highest stage. |
|---|---|---|---|---|---|---|
| | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Feb. 21, 1892 | [1] 1.96 | 8.9 | 17.5 | 8.9 | 25.6 | 26.4 |
| Apr. 8, 1895 | 1.62 | 8.8 | 13.9 | 8.6 | 22.6 | 22.7 |
| Aug. 22, 1895 | [1, 2] 2.56 | 8.6 | 21.9 | 8.6 | 30.4 | 30.5 |
| Feb. 27, 1899 | 2.13 | 11.5 | 18.7 | 8.8 | 29.6 | 30.2 |
| June 24, 1900 | [1] 2.36 | 9.8 | 19.6 | 8.3 | 29.9 | 29.4 |
| Feb. 4, 1901 | [1] 2.03 | 9.4 | 17.9 | 8.7 | 26.9 | 27.3 |
| Apr. 20, 1901 | 1.56 | 11.0 | 13.0 | 8.3 | 24.3 | 24.0 |
| June 14, 1901 | [1] 2.20 | 9.2 | 18.0 | 8.2 | 27.9 | 27.2 |
| Dec. 15, 1901 | 1.53 | 8.5 | 13.7 | 9.0 | 21.5 | 22.2 |
| Mar. 29, 1902 | 2.07 | 12.2 | 16.2 | 7.8 | 29.8 | 28.4 |
| Feb. 17, 1903 | [1] 1.68 | 14.6 | 15.3 | 9.1 | 28.9 | 29.9 |
| Feb. 28, 1903 | 1.56 | 12.5 | 14.5 | 9.3 | 25.8 | 27.0 |
| Dec. 21, 1905 | [1] 2.23 | 8.8 | 19.5 | 8.7 | 27.8 | 28.3 |
| Jan. 4, 1906 | [1] 2.21 | 10.0 | 19.6 | 8.8 | 28.8 | 29.6 |
| Jan. 23, 1906 | [2] 2.21 | 9.8 | 19.3 | 8.7 | 28.6 | 29.1 |
| Mar. 15, 1906 | 1.72 | 9.9 | 15.1 | 8.8 | 24.5 | 25.0 |
| Dec. 14, 1907 | 1.76 | 9.9 | 13.7 | 7.8 | 24.9 | 23.6 |
| Dec. 23, 1907 | 2.08 | 9.4 | 19.4 | 9.3 | 27.2 | 28.8 |
| Dec. 30, 1907 | [1] 1.65 | 13.0 | 15.0 | 9.1 | 27.0 | 28.0 |
| Feb. 1, 1908 | 2.07 | 9.7 | 17.9 | 8.6 | 27.3 | 27.6 |
| Feb. 10, 1908 | 2.14 | 10.3 | 17.8 | 8.3 | 28.5 | 28.1 |
| Dec. 22, 1908 | [1] 2.07 | 8.5 | 18.0 | 8.7 | 26.1 | 26.5 |
| May 1, 1909 | 1.96 | 10.8 | 15.1 | 7.7 | 27.5 | 25.9 |
| Jan. 29, 1910 | [1] 1.55 | 9.8 | 12.1 | 7.8 | 23.0 | 21.9 |
| Mar. 1, 1910 | 1.51 | 13.0 | 13.4 | 8.9 | 25.8 | 26.4 |
| Feb. 15, 1912 | 2.27 | 10.2 | 19.7 | 8.7 | 29.5 | 29.9 |
| Mar. 6, 1912 | 1.52 | 14.2 | 11.6 | 7.6 | 27.9 | 25.8 |
| Means | 1.93 | 10.4 | | 8.5 | | |

[1] Reports covered two dates, but rain fell in 24 hours.
[2] Slightly but not materially above limit of 2.50 inches in caption of table.
[3] Mean for 14 stations; 7 stations gave mean of 1.72 inches.

TABLE IX.—*Effect of 24-hour rains exceeding 2.50 inches over the Savannah River watershed, on river stages of 16 feet and below at Augusta, Ga.*

[Estimated rise based on values in Table XI.]

| Date. | Average rain. | Initial stage. | Estimated rise per inch of rain. | Rise per inch of rain. | Rise per inch above 29 feet.[1] | Rise to highest stage. | Estimated stage. | Highest stage. |
|---|---|---|---|---|---|---|---|---|
| | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Oct. 9, 1894 | 2.72 | 5.3 | 8.5 | 8.3 | ..... | 22.7 | 28.4 | 28.0 |
| Mar. 26, 1901 | 3.14 | 8.7 | 7.4 | 6.7 | ..... | 21.1 | 31.8 | 29.8 |
| Apr. 3, 1901 | [2] 3.03 | 12.6 | 6.6 | 6.3 | 2.5 | 19.2 | 32.6 | 31.8 |
| Feb. 24, 1902 | [2] 3.21 | 16.5 | 5.5 | 5.6 | 3.2 | 18.1 | 34.3 | 34.6 |
| Feb. 8, 1903 | [2] 3.31 | 15.2 | 5.6 | 5.4 | 2.5 | 18.0 | 33.6 | 33.2 |
| Mar. 15, 1912 | [2] 3.75 | 13.9 | 5.7 | 6.1 | [4] 4.0 | 22.9 | 35.1 | [4] 36.8 |

[1] After allowing 8.5 feet per inch of rain to 29-foot stage.
[2] Reports covered two dates, but rain fell in 24 hours.
[3] Average for 15 stations; 7 gave an average of 3.01 inches.
[4] Soil thoroughly saturated and uncultivated.

Before attempting to construct a table on which shall be represented the stage to be expected from any possible rainfall on any possible initial stage (approximately maximum run-off conditions being assumed), it is necessary to consider rains that fall when the initial stage is already 16 feet or above. Although a glance at Table X is sufficient to show the impossibility of establishing a law of averages for any of its values, as was successfully done in the tables heretofore discussed, such individual results in this table as were consistent, similar data from

other sources, and the averages in the first four tables, made possible the constructing of a forecasting table that is comprehensive and much more reliable than was thought possible when these studies were begun. Tests in practical river forecast work have demonstrated its accuracy in numerous instances when river stage and rainfall combinations were not matched by precedents, and established its superiority over the haphazard plan of searching voluminous records for precedents, or data as near precedents as may exist.

TABLE X.—*Effect of 24-hour rains over the Savannah River watershed, on river stages of 16 feet and over at Augusta, Ga.*

[Estimated rises based on values in Table XI.]

| Date. | Average rain. | Initial stage. | Estimated rise per inch of rain. | Rise per inch of rain. | Rise to highest stage. | Estimated stage. | Highest stage. |
|---|---|---|---|---|---|---|---|
| | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| July 11, 1892. | [1] 1.05 | [2] 21.8 | 4.2 | 2.7 | 2.9 | 26.3 | 24.7 |
| Aug. 6, 1894. | [1] 1.27 | [2] 20.7 | 5.3 | 2.8 | 3.6 | 27.4 | 24.3 |
| Mar. 16, 1895. | [1] 1.50 | [2] 27.6 | 1.6 | 0.6 | 0.9 | 30.3 | 28.5 |
| Feb. 9, 1896. | [3] 1.10 | 20.5 | 5.1 | 3.6 | 4.0 | 26.1 | 24.5 |
| Mar. 13, 1897. | [1] 0.92 | [2] 18.6 | 5.8 | 5.8 | 5.3 | 23.9 | 23.9 |
| Apr. 5, 1897. | [1] 1.53 | [1] 19.4 | 6.2 | 6.5 | 9.9 | 28.8 | 29.3 |
| Apr. 21, 1900. | [1] 1.89 | [2] 24.0 | 3.9 | 2.1 | 4.0 | 31.3 | 28.0 |
| Aug. 28, 1901. | 1.80 | [2] 19.0 | 6.1 | 5.6 | 10.1 | 29.9 | 29.1 |
| Feb. 11, 1903. | 1.48 | 23.0 | 4.4 | 3.9 | 5.8 | 29.5 | 28.8 |
| Mar. 23, 1903. | [1] 2.12 | [2] 23.1 | 4.2 | 2.7 | 5.8 | 32.0 | 28.9 |
| June 6, 1903. | [1] 1.35 | [2] 18.1 | 6.7 | 6.8 | 9.2 | 27.2 | 27.3 |
| Feb. 13, 1905. | [1] 1.09 | [2] 22.3 | 4.0 | 3.2 | 3.5 | 26.7 | 25.8 |
| Oct. 3, 1906. | 0.95 | 17.6 | 6.4 | 6.5 | 6.2 | 23.7 | 23.8 |
| Jan. 7, 1908. | 1.39 | 15.8 | 7.9 | 6.5 | 9.0 | 26.8 | 24.8 |

[1] Includes 30 per cent of average rainfall in area above Calhoun Falls, S. C., reported at 8 a. m. of preceding date.
[2] Stage at 8 a. m. during rainfall covering more than one 24-hour period.
[3] Reports covered two dates but rain fell in 24 hours.

## THE TABLE OF NORMAL RESULTANT STAGES.

After all known resultant stage values had been entered in a table along the side of which had been entered all stages from 8 feet to 36 feet and along the top each half-inch difference in rainfall from 1 to 5.50 inches, theoretical resultant stages were interpolated where possible and empirically estimated where interpolation was impossible. To test the general accuracy of the result and locate individual inaccuracies, the values were smoothed out by using the run-off equivalents for the various stages. The run-off equivalents in cubic feet per second for all stages from 10 to 40 feet, as furnished by the United States Geological Survey, were applied to the problem in hand, as shown in Tables XII and XIII. Only resultant stages opposite 5-foot intervals in initial stages were subjected to this test, and the intervening figures were interpolated.

All questions of doubt have been decided for the benefit of the public, and for the purpose of making estimates a little too high rather than too low. Thus, for example, although the 27 or 28-foot stage will sometimes carry off an inch of rain falling in a distinct 24-hour period after an interval between rains, yet the 29-foot stage has been assigned as the one to be expected to carry off an inch without further rise. It should be remembered, however, that the resultant stages indicated by the table are subject to increases in individual instances when unusually heavy run-off is anticipated.

TABLE XI.—*Stages normally resulting in the Savannah River at Augusta, Ga., from rainfall over the watershed, after deducting from average rainfall an allowance for ground absorption and after adding 30 per cent of previous day's average for upper section minus absorption.*

| Initial stage. | Rainfall and resulting stages. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 |
| 8 feet | 16.5 | 20.8 | 25.0 | 29.0 | 31.1 | 32.9 | 34.4 | 35.5 | 36.6 | 37.7 |
| 9 feet | 17.5 | 21.8 | 26.0 | 29.5 | 31.4 | 33.1 | 34.5 | 35.7 | 36.8 | 37.8 |
| 10 feet | 18.5 | 22.8 | 27.0 | 29.8 | 31.7 | 33.3 | 34.7 | 35.9 | 37.0 | 37.9 |
| 11 feet | 19.5 | 23.8 | 28.0 | 30.2 | 32.0 | 33.5 | 34.9 | 36.1 | 37.2 | 38.1 |
| 12 feet | 20.5 | 24.8 | 29.0 | 30.6 | 32.3 | 33.7 | 35.1 | 36.3 | 37.4 | 38.3 |
| 13 feet | 21.5 | 25.8 | 29.4 | 31.0 | 32.7 | 34.1 | 35.4 | 36.5 | 37.6 | 38.5 |
| 14 feet | 22.5 | 26.7 | 29.7 | 31.4 | 33.1 | 34.5 | 35.7 | 36.8 | 37.8 | 38.7 |
| 15 feet | 23.0 | 27.5 | 30.0 | 31.8 | 33.5 | 34.9 | 36.0 | 37.1 | 38.0 | 38.9 |
| 16 feet | 23.5 | 27.9 | 30.2 | 32.0 | 33.7 | 35.0 | 36.2 | 37.2 | 38.1 | 39.0 |
| 17 feet | 24.0 | 28.2 | 30.4 | 32.2 | 33.9 | 35.1 | 36.3 | 37.3 | 38.2 | 39.1 |
| 18 feet | 24.4 | 28.4 | 30.6 | 32.4 | 34.0 | 35.2 | 36.4 | 37.4 | 38.3 | 39.2 |
| 19 feet | 24.8 | 28.6 | 30.8 | 32.6 | 34.1 | 35.3 | 36.5 | 37.5 | 38.4 | 39.3 |
| 20 feet | 25.2 | 28.8 | 31.0 | 32.8 | 34.2 | 35.4 | 36.6 | 37.6 | 38.5 | 39.4 |
| 21 feet | 25.6 | 29.1 | 31.2 | 32.9 | 34.4 | 35.6 | 36.7 | 37.7 | 38.6 | 39.5 |
| 22 feet | 26.0 | 29.4 | 31.4 | 33.0 | 34.5 | 35.7 | 36.8 | 37.8 | 38.7 | 39.6 |
| 23 feet | 26.4 | 29.6 | 31.6 | 33.1 | 34.6 | 35.8 | 36.9 | 37.9 | 38.8 | 39.7 |
| 24 feet | 26.8 | 29.8 | 31.7 | 33.2 | 34.7 | 35.9 | 37.0 | 38.0 | 38.9 | 39.7 |
| 25 feet | 27.2 | 30.0 | 31.8 | 33.4 | 34.9 | 36.0 | 37.1 | 38.0 | 38.9 | 39.7 |
| 26 feet | 27.6 | 30.1 | 31.9 | 33.5 | 34.9 | 36.1 | 37.2 | 38.1 | 39.0 | 39.8 |
| 27 feet | 28.0 | 30.2 | 32.0 | 33.6 | 35.0 | 36.1 | 37.2 | 38.1 | 39.0 | 39.9 |
| 28 feet | 28.5 | 30.3 | 32.1 | 33.7 | 35.1 | 36.2 | 37.3 | 38.2 | 39.1 | 39.9 |
| 29 feet | 29.0 | 30.5 | 32.2 | 33.9 | 35.2 | 36.3 | 37.4 | 38.3 | 39.2 | 40.0 |
| 30 feet | 30.0 | 30.7 | 32.5 | 34.1 | 35.3 | 36.4 | 37.5 | 38.4 | 39.3 | 40.0 |
| 31 feet | 31.0 | 31.6 | 33.1 | 34.6 | 35.8 | 36.9 | 37.9 | 38.8 | 39.6 | 40.2 |
| 32 feet | 32.0 | 32.5 | 33.7 | 35.1 | 36.3 | 37.3 | 38.3 | 39.1 | 39.8 | 40.5 |
| 33 feet | 33.0 | 33.4 | 34.3 | 35.6 | 36.7 | 37.7 | 38.7 | 39.4 | 40.0 | 40.7 |
| 34 feet | 34.0 | 34.2 | 34.9 | 36.1 | 37.1 | 38.1 | 39.0 | 39.7 | 40.3 | 40.9 |
| 35 feet | 35.0 | 35.0 | 35.5 | 36.5 | 37.5 | 38.5 | 39.3 | 40.0 | 40.6 | 41.2 |
| 36 feet | 36.0 | 36.0 | 36.0 | 36.9 | 37.9 | 38.9 | 39.6 | 40.3 | 40.9 | 41.4 |

CORRECTIONS TO BE APPLIED TO TABLE XI AFTER THE AUGUSTA LEVEE IS BUILT.

[Furnished by Chief Engineer, River and Canal Commission, Augusta, Ga.]

| Present reading. | Reading in levee. | Present reading. | Reading in levee. |
|---|---|---|---|
| | *Feet.* | | *Feet.* |
| 34 feet | 34.0 | 38 feet | 40.0 |
| 35 feet | 35.6 | 39 feet | 42.0 |
| 36 feet | 36.9 | 40 feet | [1] 44.3 |
| 37 feet | 38.3 | 41 feet | [1] 46.0 |

[1] Estimated.

TABLE XII.—*Discharge in cubic feet per second corresponding to river stages in the Savannah River at Augusta, Ga.*

[Furnished by the United States Geological Survey.]

| River stage. | Discharge per second. | River stage. | Discharge per second. | River stage. | Discharge per second. | River stage. | Discharge per second. |
|---|---|---|---|---|---|---|---|
| | *Cu. feet.* | | *Cu. feet.* | | *Cu. feet.* | | *Cu. feet.* |
| 10 feet | 10,000 | 18 feet | 33,500 | 26 feet | 76,100 | 34 feet | 151,000 |
| 11 feet | 12,200 | 19 feet | 37,500 | 27 feet | 83,500 | 35 feet | 165,000 |
| 12 feet | 14,600 | 20 feet | 41,800 | 28 feet | 91,500 | 36 feet | 180,500 |
| 13 feet | 17,200 | 21 feet | 46,500 | 29 feet | 100,000 | 37 feet | 190,500 |
| 14 feet | 20,000 | 22 feet | 51,600 | 30 feet | 109,000 | 38 feet | 216,000 |
| 15 feet | 23,000 | 23 feet | 57,100 | 31 feet | 118,500 | 39 feet | 236,000 |
| 16 feet | 26,300 | 24 feet | 63,000 | 32 feet | 128,500 | 40 feet | 260,000 |
| 17 feet | 29,800 | 25 feet | 69,300 | 33 feet | 139,500 | | |

TABLE XIII.—*Increase in run-off in cubic feet per second at Augusta, Ga., resulting from 24-hour rainfall over the Savannah River watershed.*

| Rain. | River stage. | Run-off per second. | Increase, run-off per second. | Rain. | River stage. | Run-off per second. | Increase, run-off per second. |
|---|---|---|---|---|---|---|---|
| *Inches.* | *Feet.* | *Cu. feet.* | *Cu. feet.* | *Inches.* | *Feet.* | *Cu. feet.* | *Cu. feet.* |
| ..... | 10.0 | 10,000 | ..... | ..... | 25.0 | 69,300 | ..... |
| 0.50 | ..... | ..... | ..... | 0.50 | ..... | ..... | ..... |
| 1.00 | 18.5 | 35,500 | 25,500 | 1.00 | 27.2 | 85,000 | 15,800 |
| 1.50 | 22.8 | 56,000 | 20,500 | 1.50 | 30.0 | 109,000 | 24,000 |
| 2.00 | 27.0 | 83,500 | 27,500 | 2.00 | 31.8 | 127,000 | 18,000 |
| 2.50 | 29.8 | 107,200 | 23,700 | 2.50 | 33.4 | 145,000 | 18,000 |
| 3.00 | 31.7 | 125,200 | 18,000 | 3.00 | 34.9 | 163,000 | 18,000 |
| 3.50 | 33.3 | 143,200 | 18,000 | 3.50 | 36.0 | 181,000 | 18,000 |
| 4.00 | 34.7 | 161,200 | 18,000 | 4.00 | 37.1 | 199,000 | 18,000 |
| 4.50 | 35.9 | 179,200 | 18,000 | 4.50 | 38.0 | 217,000 | 18,000 |
| 5.00 | 37.0 | 197,200 | 18,000 | 5.00 | 38.9 | 235,000 | 18,000 |
| 5.50 | 37.9 | 215,200 | 18,000 | 5.50 | 39.7 | 253,000 | 18,000 |
| ..... | 15.0 | 23,000 | ..... | ..... | 30.0 | 109,000 | ..... |
| 0.50 | ..... | ..... | ..... | 0.50 | ..... | ..... | ..... |
| 1.00 | 23.0 | 57,100 | 34,100 | 1.00 | 30.0 | 109,000 | 00,000 |
| 1.50 | 27.5 | 87,500 | 30,400 | 1.50 | 30.7 | 116,000 | 7,000 |
| 2.00 | 30.0 | 109,000 | 21,500 | 2.00 | 32.5 | 134,000 | 18,000 |
| 2.50 | 31.8 | 127,000 | 18,000 | 2.50 | 34.7 | 152,000 | 18,000 |
| 3.00 | 33.5 | 145,000 | 18,000 | 3.00 | 35.3 | 170,000 | 18,000 |
| 3.50 | 34.9 | 163,000 | 18,000 | 3.50 | 36.4 | 188,000 | 18,000 |
| 4.00 | 36.0 | 181,000 | 18,000 | 4.00 | 37.5 | 206,000 | 18,000 |
| 4.50 | 37.1 | 199,000 | 18,000 | 4.50 | 38.4 | 224,000 | 18,000 |
| 5.00 | 38.0 | 217,000 | 18,000 | 5.00 | 39.3 | 242,000 | 18,000 |
| 5.50 | 38.9 | 235,000 | 18,000 | 5.50 | 40.0 | 260,000 | 18,000 |
| ..... | 20.0 | 41,800 | ..... | ..... | 35.0 | 165,000 | ..... |
| 0.50 | ..... | ..... | ..... | 0.50 | ..... | ..... | ..... |
| 1.00 | 25.2 | 70,700 | 28,900 | 1.00 | 35.0 | 165,000 | 00,000 |
| 1.50 | 28.8 | 98,300 | 27,600 | 1.50 | 35.0 | 165,000 | 00,000 |
| 2.00 | 31.0 | 118,500 | 20,200 | 2.00 | 35.5 | 175,000 | 10,000 |
| 2.50 | 32.8 | 136,500 | 18,000 | 2.50 | 36.5 | 189,000 | 14,000 |
| 3.00 | 34.2 | 154,500 | 18,000 | 3.00 | 37.5 | 207,000 | 18,000 |
| 3.50 | 35.4 | 172,500 | 18,000 | 3.50 | 38.5 | 225,000 | 18,000 |
| 4.00 | 36.6 | 190,500 | 18,000 | 4.00 | 39.3 | 243,000 | 18,000 |
| 4.50 | 37.6 | 208,500 | 18,000 | 4.50 | 40.0 | 261,000 | 18,000 |
| 5.00 | 38.5 | 226,500 | 18,000 | 5.00 | 40.6 | 279,000 | 18,000 |
| 5.50 | 39.4 | 244,500 | 18,000 | 5.50 | 41.2 | 297,000 | 18,000 |

TABLE XIV.—*Normal rise in the Savannah River at Augusta, Ga., per average inch of rainfall over the watershed, in 24 hours, when the soil is moist.*

[Values derived from Table XI.]

| Initial stage. | Rainfall, inches, and Rise in feet per inch of rain. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 |
| 8 feet | 8.5 | 8.5 | 8.5 | 8.4 | 7.7 | 7.1 | 6.6 | 6.1 | 5.7 | 5.4 |
| 9 feet | 8.5 | 8.5 | 8.5 | 8.2 | 7.5 | 6.9 | 6.4 | 5.9 | 5.6 | 5.2 |
| 10 feet | 8.5 | 8.5 | 8.5 | 7.9 | 7.2 | 6.7 | 6.2 | 5.8 | 5.4 | 5.1 |
| 11 feet | 8.5 | 8.5 | 8.5 | 7.7 | 7.0 | 6.4 | 6.0 | 5.6 | 5.2 | 4.9 |
| 12 feet | 8.5 | 8.5 | 8.5 | 7.4 | 6.8 | 6.2 | 5.8 | 5.4 | 5.1 | 4.8 |
| 13 feet | 8.5 | 8.5 | 8.2 | 7.2 | 6.6 | 6.0 | 5.6 | 5.2 | 4.9 | 4.6 |
| 14 feet | 8.5 | 8.5 | 7.8 | 7.0 | 6.4 | 5.9 | 5.4 | 5.1 | 4.8 | 4.5 |
| 15 feet | 8.0 | 8.3 | 7.5 | 6.7 | 6.2 | 5.7 | 5.2 | 4.9 | 4.6 | 4.3 |
| 16 feet | 7.5 | 7.8 | 7.1 | 6.4 | 5.9 | 5.4 | 5.0 | 4.7 | 4.4 | 4.2 |
| 17 feet | 7.0 | 7.5 | 6.7 | 6.1 | 5.6 | 5.2 | 4.8 | 4.5 | 4.2 | 4.0 |
| 18 feet | 6.4 | 7.0 | 6.3 | 5.8 | 5.3 | 4.9 | 4.6 | 4.3 | 4.1 | 3.9 |
| 19 feet | 5.8 | 6.4 | 5.9 | 5.4 | 5.0 | 4.7 | 4.4 | 4.1 | 3.9 | 3.7 |
| 20 feet | 5.2 | 5.9 | 5.5 | 5.1 | 4.7 | 4.4 | 4.2 | 3.9 | 3.7 | 3.5 |
| 21 feet | 4.6 | 5.4 | 5.1 | 4.8 | 4.5 | 4.2 | 3.9 | 3.7 | 3.5 | 3.4 |
| 22 feet | 4.0 | 4.9 | 4.7 | 4.4 | 4.2 | 3.9 | 3.7 | 3.5 | 3.3 | 3.2 |
| 23 feet | 3.4 | 4.4 | 4.3 | 4.0 | 3.9 | 3.7 | 3.5 | 3.3 | 3.2 | 3.0 |
| 24 feet | 2.8 | 3.9 | 3.8 | 3.7 | 3.6 | 3.4 | 3.2 | 3.1 | 3.0 | 2.9 |
| 25 feet | 2.2 | 3.3 | 3.4 | 3.3 | 3.3 | 3.1 | 3.0 | 3.0 | 2.8 | 2.7 |
| 26 feet | 1.6 | 2.7 | 3.0 | 3.0 | 3.0 | 2.9 | 2.8 | 2.7 | 2.6 | 2.5 |
| 27 feet | 1.0 | 2.1 | 2.5 | 2.6 | 2.7 | 2.6 | 2.5 | 2.5 | 2.4 | 2.3 |
| 28 feet | 0.5 | 1.5 | 2.0 | 2.3 | 2.4 | 2.3 | 2.3 | 2.3 | 2.2 | 2.2 |
| 29 feet | 0.0 | 1.0 | 1.6 | 2.0 | 2.1 | 2.1 | 2.1 | 2.1 | 2.0 | 2.0 |
| 30 feet | 0.0 | 0.5 | 1.2 | 1.6 | 1.8 | 1.8 | 1.9 | 1.9 | 1.9 | 1.8 |
| 31 feet | 0.0 | 0.4 | 1.0 | 1.4 | 1.6 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 |
| 32 feet | 0.0 | 0.3 | 0.8 | 1.2 | 1.4 | 1.5 | 1.6 | 1.6 | 1.6 | 1.5 |
| 33 feet | 0.0 | 0.3 | 0.6 | 1.0 | 1.2 | 1.3 | 1.4 | 1.4 | 1.4 | 1.4 |
| 34 feet | 0.0 | 0.1 | 0.4 | 0.8 | 1.0 | 1.2 | 1.2 | 1.3 | 1.3 | 1.3 |
| 35 feet | 0.0 | 0.0 | 0.2 | 0.6 | 0.8 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 |
| 36 feet | 0.0 | 0.0 | 0.0 | 0.4 | 0.6 | 0.8 | 0.9 | 1.0 | 1.0 | 1.1 |

## ABSORPTION OF MOISTURE BY THE SOIL.

Absorption varies with ground conditions as to moisture and cultivation, and with rate of rainfall. Slowness of rain on moist or even wet soil causes large reductions from the surface run-off, and on loose soil that is either dry or only slightly moist such rain will be almost entirely absorbed. Heavy rain on any kind of soil has a relatively high percentage of run-off, particularly in a hilly country such as that in the Savannah watershed.

It is occasionally commented upon by those familiar with the peculiarities of the river, that with similar rainfall a greater rise often occurs from very dry soil than from soil previously dampened by precipitation after a long dry spell. This discloses an interesting truth regarding the absorption of moisture by the soil. As Widtsoe, in "Dry Farming," expresses it, "very dry soil and moisture repel each other." The principle is illustrated by the familiar experiment of placing a dry sponge and moist sponge in water at the same time. The moist sponge is instantly saturated, while the dry one takes in the water slowly at first and is not saturated for some little time.

From measurements made by the Bureau of Plant Industry, it appears that excessive precipitation should give a heavier surface run-off from the dust mulch land of late spring and early summer than from the dry laid-by land of late summer and early autumn. L. J. Briggs and J. O. Belz, in Bureau of Plant Industry Bulletin No. 188, report measurements in Utah which show that during a heavy rain of 2.5 inches in four hours, summer-tilled land was so quickly packed by the force of the downpour that it absorbed only 0.5 inch, or 20 per cent of the water, while adjacent wheat-stubble land which was dry and contained many surface cracks, absorbed 1.5 inches, or 60 per cent. From other experiments reported by the same writers it appears that this loss of 80 per cent on tilled land is an extreme case, but the flow would be heavier from the slopes of the Savannah Valley farms than from the level land on which the reported experiments were made.

Many rains averaging more than an inch for the watershed are negligible so far as the forecasting of river stages of 18 feet and over is concerned. Averages, especially in warm weather, must usually be subjected to reductions of from 0.25 inch to 1 inch before being carried to the above given forecasting table. When an additional reduction must be allowed in the estimated rise on account of erratic distribution of summer showers it is often found to be unnecessary to make an official prediction on rains that if distributed generally would give a high stage.

On the morning of September 23, 1897, the rainfall reports averaged 2.22 inches of rain, which had fallen at a steady rate for nearly 24 hours on very dry soil. The resulting rise in the Savannah at Augusta was equivalent to the theoretical rise on only 0.92 inch of rain. The 2.51 inches of rainfall reported June 13, 1906, produced only such a rise as would follow 1.46 inches of rain falling at a normal rate on moist soil. Thus it is seen that heavy rains falling at a steady rate may be largely absorbed by a thirsty soil.

To attempt to lay down fixed rules for allowances to be made for ground absorption would be useless. A little experience and the knowledge and trained judgment of a person familiar with meteorological work are essential. Much depends upon the season of the year, the character of the weather as to temperature, cloudiness, wind, and light rains, and the condition of the soil as to cultivation. The records should be carefully studied by the forecaster. Table XV and diagrams on file at Augusta are designed to supplement a careful perusal of the daily records. It has been found that the river gage readings at Carlton, Ga., and Calhoun Falls, S. C., are sometimes helpful.

It may be well to comment at this point on the fact that deficient river rises from slow rainfall on saturated soil are followed by gradual return to normal stages. Occasionally this delayed run-off, which is probably partly surface flow and partly groundwater flow, combines with the rise

from rains a day or two later and gives a stage somewhat higher than would otherwise occur. In a few instances it has been sufficiently pronounced to delay by as much as 24 hours the highest stage following a 24-hour rain. In such cases the crest agrees closely with that indicated by the forecast table, a deficient 24-hour rise being augmented by the delayed run-off.

### EFFECT OF RAINFALL DISTRIBUTION ON THE HEIGHT OF THE FLOOD CREST.

In selecting stations that are to report rainfall for river-stage forecasting it is of the utmost importance to maintain at all times a consistent horizontal distribution. This does not mean that the stations should be equidistant, for in such an arrangement the drainage areas of major importance would be given the same weight as relatively insignificant areas. Over basins drained by larger and more numerous streams more stations should be placed than over those of lesser importance in accumulating and discharging the surface run-off from rainfall. This work properly and thoroughly done disposes of the question of rainfall distribution so far as the importance of one station over another is concerned and incidentally eliminates from the problem all consideration of topography and other physical peculiarities of a permanent character.

When it is stated that the drainage basin of the Savannah River above Augusta must be divided into two sections, from one of which the crest reaches Augusta in from 18 to 24 hours and from the other in about 40 to 48 hours, it is at first difficult to see why the stations in the section above Calhoun Falls should be given the same individual weight in computing the rise to be expected from a 24-hour rain as are the stations over the area from which the crest reaches Augusta in much less time. However, experimental forecasts in which the upper stations are ignored nearly always result in a decided loss of accuracy.

It appears that the run-off from heavy rains in the upper section of the watershed supports the water in the neighboring portions of the streams, and, by preventing it from flattening out, contributes indirectly to the ultimate stage. When there is no such support, the maximum stage at Augusta is lower in proportion to the deficiency of precipitation in the upper section. When precipitation is decidedly heavier in the upper section than in the lower, its volume is sometimes sufficient to continue the rise beyond the usual time and give a crest higher than that indicated by the average rainfall for the watershed. Such an occurrence is somewhat rare, but it may be anticipated by adding to the average for all stations 30 per cent of the difference between the average for the upper stations and the average for all stations.

From what has been said it is obvious that when general rain falls over the Savannah Valley the stage to be predicted can be determined without applying to the average rainfall any modification other than an allowance for absorption by the ground. This is true even though there be wide differences in the amounts at the various stations.

Frequently, however, summer showers do not distribute themselves generally over the watershed, and the run-off from wide areas may be either insignificant or entirely lacking. They follow no rule such as has been explained for general rainfall, and it is always necessary to determine as nearly as possible to what extent the distribution is erratic.

When the rains have fallen long enough before the receipt of the reports for the water to have taken effect at Carlton and Calhoun Falls, the river readings at those points are very helpful. It has also been found of assistance to utilize the reports from cotton region reporting stations. A knowledge of general meteorological conditions as shown by the daily weather map and an understanding of the significance of those conditions are required.

The above-mentioned aids in determining the character of the distribution are, however, merely supplementary to the following rules, which have been ascertained by practical experience, though the river-gage relations are often of almost equal importance and are sometimes the main deciding factor.

These rules are applicable only to erratic summer thunderstorms.

1. When the average rainfall is 2 inches it is very rarely advisable to reduce the estimate on account of irregularities in distribution.

2. When the rainfall averages 1.50 inches or somewhat less:

(*a*) When only 2 stations in 10 have less than 0.50 inch the distribution should be considered general and no allowance made for erratic distribution.

(*b*) When 3 stations in 10 have less than 0.50 inch allow three-fourths to full value, after making allowance for ground absorption.

(*c*) When 4 or 5 stations in 10 have less than 0.50 inch allow for a rise of only one-half value, unless 2 or more of the other stations have 3 or more inches of rain, when the estimate should be three-fourths to full value, in the discretion of the forecaster, after making allowance for ground absorption.

Before closing the subject of rainfall distribution it may be well to mention the fact that when one or two stations in the upper section of the watershed report 3.50 to 5 inches of rain that is apparently local in character the heavy downpours are at times of sufficient extent to cause a moderate rise that culminates in Augusta in 40 to 48 hours. In order to anticipate such rises, it is necessary to have the river stations report stages at 5 p. m. and the next 8 a. m.

TABLE XV.—*Effect of ground absorption and slow and erratic run-off on the relation between 24-hour rains and river stages at Augusta, Ga.*

[Normal rise per inch of rain, 8.5 feet.]

| Date. | Average rain. | Absorption, etc. | Initial stage. | Normal rise. | Actual rise. | Highest stage. | Condition of soil. | Character of rain. |
|---|---|---|---|---|---|---|---|---|
| | *Inches.* | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | | |
| May 3, 1893 | 1.12 | 0.57 | 7.6 | 9.5 | 4.8 | 12.4 | Dry | Showers. |
| Oct. 13, 1893 | 1.82 | .35 | 6.3 | 15.5 | 12.5 | 18.8 | do | Steady. |
| Sept. 18, 1894 | 1.14 | .21 | 5.8 | 9.7 | 7.9 | 13.7 | do | Slow. |
| Nov. 3, 1894 | 1.28 | .30 | 7.0 | 10.9 | 8.3 | 15.3 | do | Showers. |
| Jan. 17, 1896 | 1.63 | .45 | 6.5 | 13.8 | 10.2 | 16.7 | do | Steady. |
| Feb. 6, 1896 | 1.56 | .30 | 12.0 | 13.3 | 10.7 | 22.7 | Moist | Do. |
| Jan. 14, 1897 | 1.28 | .50 | 5.8 | 10.9 | 6.6 | 12.4 | Dry | Do. |
| Feb. 2, 1897 | 1.18 | .15 | 7.2 | 10.0 | 8.8 | 16.0 | Moist | Do. |
| Feb. 6, 1897 | 2.31 | .45 | 11.6 | 19.4 | 15.9 | 27.5 | do | Do. |
| July 18, 1897 | 1.91 | .65 | 5.7 | 16.2 | 10.9 | 16.6 | Dry | Do. |
| Sept. 23, 1897 | 2.22 | 1.30 | 4.5 | 18.9 | 8.0 | 12.5 | do | Do. |
| Nov. 27, 1897 | 1.25 | .85 | 5.0 | 12.6 | 3.6 | 8.6 | do | Do. |
| Apr. 5, 1898 | 1.82 | .65 | 8.5 | 15.5 | 10.0 | 18.5 | Moist | Do. |
| Apr. 24, 1898 | 1.06 | .50 | 6.8 | 9.0 | 5.0 | 11.8 | do | Do. |
| Jan. 11, 1899 | 0.90 | .50 | 12.8 | 7.6 | 4.4 | 17.2 | do | Slow. |
| Mar. 31, 1899 | 0.99 | .27 | 13.5 | 8.4 | 6.1 | 19.6 | do | Showers. |
| July 27, 1899 | 0.95 | .36 | 7.0 | 8.1 | 5.7 | 12.7 | Dry | Steady. |
| Aug. 30, 1899 | 1.18 | .93 | 9.2 | 10.0 | 2.2 | 11.4 | Wet | Showers. |
| Mar. 16, 1900 | 1.20 | .30 | 10.0 | 10.2 | 7.8 | 17.8 | Moist | Steady. |
| June 17, 1900 | 1.45 | .47 | 11.5 | 12.3 | 8.3 | 19.8 | do | Showers. |
| July 30, 1900 | 1.19 | .87 | 11.0 | 10.1 | 2.7 | 13.7 | do | Steady. |
| Feb. 9, 1901 | 0.90 | .45 | 12.5 | 7.6 | 3.6 | 16.1 | do | Do. |
| June 7, 1901 | 1.35 | .56 | 9.7 | 11.5 | 6.7 | 16.4 | Dry | Showers. |
| June 16, 1902 | 1.83 | 1.08 | 9.5 | 15.6 | 6.4 | 15.9 | do | Do. |
| July 14, 1903 | 1.54 | 1.00 | 9.7 | 13.1 | 4.6 | 14.3 | do | Do. |

TABLE XV.—*Effect of ground absorption and slow and erratic run-off on the relation between 24-hour rains and river stages at Augusta, Ga.*—Con.

| Date. | Average rain. | Absorption, etc. | Initial stage. | Normal rise. | Actual rise. | Highest stage. | Condition of soil. | Character of rain. |
|---|---|---|---|---|---|---|---|---|
| | *Inches.* | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | | |
| Jan. 23, 1904 | 1.28 | 0.60 | 7.3 | 10.9 | 5.7 | 13.0 | Dry... | Showers. |
| Dec. 3, 1905 | 2.50 | .85 | 6.0 | 21.2 | 13.9 | 19.9 | ...do... | Steady. |
| Dec. 9, 1905 | 1.79 | .60 | 8.6 | 15.2 | 10.2 | 18.8 | Moist. | Slow. |
| May 7, 1906 | 1.12 | .70 | 9.0 | 9.5 | 3.7 | 12.7 | Dry... | Do. |
| May 27, 1906 | 1.30 | .74 | 8.2 | 11.0 | 4.8 | 13.0 | ...do... | Showers. |
| June 13, 1906 | 2.51 | 1.05 | 8.8 | 21.3 | 12.2 | 21.0 | ...do... | Steady. |
| July 9, 1906 | 1.36 | .35 | 10.0 | 11.6 | 8.5 | 18.5 | ...do... | Showers. |
| July 15, 1906 | 1.69 | .28 | 9.1 | 14.4 | 12.0 | 21.1 | Moist. | Do. |
| July 30, 1906 | 1.07 | .22 | 10.8 | 9.4 | 7.2 | 18.5 | Dry... | Do. |
| Apr. 23, 1907 | 1.73 | .38 | 8.0 | 14.7 | 11.5 | 19.5 | ...do... | Steady. |
| June 1, 1907 | 1.20 | .35 | 7.8 | 10.2 | 7.2 | 15.0 | ...do... | Showers. |
| June 28, 1907 | 1.57 | .78 | 7.5 | 13.3 | 6.7 | 14.2 | Moist. | Steady. |
| Sept. 23, 1907 | 1.49 | .32 | 5.9 | 12.7 | 9.9 | 15.8 | Dry... | Showers. |
| Mar. 21, 1908 | 1.17 | .65 | 9.5 | 9.9 | 4.3 | 13.8 | Moist. | Steady. |
| June 15, 1908 | 1.00 | .53 | 8.8 | 8.5 | 4.0 | 12.8 | Dry... | Showers. |
| Nov. 14, 1908 | 1.11 | .65 | 8.6 | 9.4 | 3.8 | 12.4 | Moist. | Steady. |
| Aug. 3, 1909 | 1.76 | .54 | 10.1 | 15.0 | 10.4 | 20.5 | ...do... | Showers. |
| Sept. 18, 1909 | 1.06 | .58 | 14.9 | 9.0 | 3.9 | 18.8 | ...do... | Do. |
| Oct. 15, 1909 | 1.43 | .44 | 8.3 | 12.2 | 8.6 | 16.9 | Dry... | Do. |
| Apr. 17, 1910 | 1.76 | .95 | 8.2 | 15.0 | 7.0 | 15.2 | ...do... | Steady. |
| Oct. 8, 1910 | 2.04 | 1.20 | 10.9 | 17.3 | 7.2 | 18.1 | ...do... | Do. |
| Mar. 27, 1911 | 1.14 | .45 | 7.5 | 9.7 | 6.0 | 13.5 | ...do... | Do. |
| Apr. 8, 1911 | 1.02 | .58 | 13.2 | 8.7 | 4.6 | 17.8 | Moist. | Showers. |
| July 14, 1911 | 1.23 | .62 | 8.4 | 9.4 | 5.2 | 13.6 | Dry... | Do. |
| Oct. 22, 1911 | 1.58 | .75 | 8.5 | 13.4 | 6.9 | 15.4 | Moist. | Slow. |
| Oct. 28, 1911 | 1.47 | .62 | 8.7 | 12.5 | 7.2 | 15.9 | ...do... | Steady. |
| Nov. 7, 1911 | 1.10 | .35 | 7.0 | 9.4 | 6.5 | 13.5 | ...do... | Do. |
| Nov. 9, 1911 | 1.49 | .60 | 13.5 | 12.7 | 7.1 | 20.6 | Wet... | Slow. |
| Jan. 9, 1912 | 1.26 | .25 | 10.8 | 10.7 | 8.4 | 19.2 | ...do... | Steady. |
| Jan. 30, 1912 | 1.97 | .32 | 9.2 | 16.7 | 14.0 | 23.2 | ...do... | Do. |

## EXTENSION OF THE RIVER FORECAST SCHEME BEYOND ONE 24-HOUR PERIOD.

When rain occurs on two or more successive days it is necessary on the second and subsequent days to add to the average rainfall for all of the stations 30 per cent of the average reported from the upper section on the previous day. When it is necessary to make allowances for ground absorption and for erratic run-off, such allowances should be applied to the averages before any other computations are attempted. To determine the average for the upper section the rainfall measurements for Calhoun Falls, S. C., Carlton, Ga., Anderson, S. C., Gillsville, and Toccoa, Ga., are used.

The application of the rule in practice is exemplified in Table XVI, in which computations are given for all long rains that have resulted in stages of 25 feet or over since the beginning of the record in 1892. Through good fortune, averages for four excellently distributed stations are also available for the 1888 freshet, the stations being Augusta, Ga., Washington, Ga., Greenwood, S. C., and Toccoa, Ga.

The following comments and rules are of utmost importance in handling river forecast work at Augusta:

1. When more rain is expected to fall during the day, from 1 to 3 feet may be added to the estimate based on the morning reports, but when the river is above 15 feet or when there is a possibility of general heavy rains, special observations should be telegraphed from all stations at 2 p. m. or 5 p. m., or both. At times the river responds so quickly to the rainfall that it is no easy matter, even by the liberal use of special observations, to make a forecast that shall be both timely and accurate.

2. It is important to distinguish between rains occurring in two separate 24-hour periods and those falling within 24 hours though partly before and partly after 8 a. m. A compromise is occasionally advisable, especially when the rainfall is continuous.

3. The first estimate should always be based on the initial stage, i. e., the stage before the rains under consideration began to affect the river, even though there is already a considerable increase in the river stage.

4. When rainfall reports are received for an additional 24-hour period and the river stage is lower than indicated by the rainfall reports of the previous morning, base the forecast on the 8 a. m. stage, unless there is reason to believe the rise from the rains reported the previous morning has not approximately reached its crest.

5. When the 8 a. m. stage exceeds the estimate based on the reports of the previous morning, and the excess rise *can not* be charged to the effect of the rains represented by the current reports, use the 8 a. m. stage as the basis of the estimate.

6. When the 8 a. m. stage exceeds the estimate based on the reports of the previous morning and the excess rise *is* chargeable to the rains represented by the current reports, use as the basis of estimate the theoretical stage indicated by the reports of the previous morning.

7. When handling special rainfall reports, i. e., reports of observations taken at any other hour than 8 a. m., it is usually advisable to add to the average of the special reports 30 per cent of the 8 a. m. average for the upper section of the watershed and base the computation on the theoretical estimate resulting from the 8 a. m. reports. It is, however, sometimes better to consider the rain during the interval between 8 a. m. and the hour of the special observation a continuation of the rains reported at 8 a. m. and treat the sum of the two averages as rainfall within 24 hours. A compromise between these two methods may be resorted to in case of doubt.

TABLE XVI.—*Effect of rainfall over the watershed in two or more 24-hour periods on Savannah River stages at Augusta, Ga.*

[Estimates of rise based on Table XI after deducting allowances for ground absorption and slow and erratic run-off from rainfall averages.]

| Date. | Average rain. | Absorption, etc. | Plus 30 per cent last upper. | Average, upper section. | Initial stage. | Stage at 8 a. m. | Estimated stage. | Highest stage. |
|---|---|---|---|---|---|---|---|---|
| | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Sept. 9, 1888 | 2.34 | 0 | ..... | 1.40 | 23.0 | 23.5 | 32.7 | ..... |
| Sept. 10, 1888 | 3.98 | 0 | 4.40 | 1.46 | ..... | 34.7 | [1] 39.2 | 38.7 |
| Jan. 18, 1892 | 1.43 | .19 | ..... | 1.04 | 17.0 | 17.0 | 26.2 | ..... |
| Jan. 19, 1892 | 1.45 | 0 | 1.76 | 2.03 | ..... | 26.2 | 31.0 | ..... |
| Jan. 20, 1892 | 0.94 | 0 | 1.55 | 0.87 | ..... | 31.0 | 31.8 | 32.8 |
| Mar. 24, 1892 | 0.52 | 0 | ..... | 0.29 | 8.3 | 8.3 | 12.7 | ..... |
| Mar. 25, 1892 | 0.57 | 0 | 0.66 | 0.36 | ..... | 13.9 | [1] 18.3 | ..... |
| Mar. 26, 1892 | 1.76 | .53 | 1.34 | 1.51 | ..... | 18.8 | 27.1 | 26.6 |
| Feb. 12, 1893 | 0.81 | 0 | ..... | 0.67 | 9.8 | 9.8 | 16.7 | ..... |
| Feb. 13, 1893 | 1.03 | 0 | 1.23 | 1.92 | ..... | 19.2 | [1] 25.8 | 25.4 |
| Dec. 11, 1894 | 0.71 | .53 | 0.95 | 1.04 | 6.5 | 6.5 | 10.1 | ..... |
| Dec. 12, 1894 | 1.84 | 0 | 1.99 | 2.57 | ..... | 10.1 | 27.0 | 26.2 |
| Jan. 9, 1895 | 1.47 | .50 | ..... | 1.57 | 7.7 | 9.3 | 15.9 | ..... |
| Jan. 10, 1895 | 2.57 | .30 | 2.09 | 1.90 | ..... | 25.0 | [1] 30.5 | 30.5 |
| Mar. 13, 1895 | 0.85 | 0 | ..... | 0.79 | 11.6 | 11.6 | 18.8 | ..... |
| Mar. 14, 1895 | 0.74 | 0 | 0.98 | 0.90 | ..... | 22.5 | [1] 24.8 | ..... |
| Mar. 15, 1895 | 0.99 | 0 | 1.24 | 0.85 | ..... | 27.0 | [1] 28.5 | ..... |
| Mar. 16, 1895 | 1.24 | .50 | 1.00 | 0.96 | ..... | 27.6 | 28.3 | 28.5 |
| July 7, 1896 | 1.89 | 1.00 | ..... | 1.60 | 6.3 | 8.8 | 13.9 | ..... |
| July 8, 1896 | 3.34 | 1.82 | 2.00 | 1.88 | ..... | 22.4 | [1] 29.2 | ..... |
| July 9, 1896 | 1.59 | 0 | 1.61 | 1.16 | ..... | 29.2 | 30.9 | [2] 30.5 |
| Mar. 12, 1897 | 0.79 | 0 | ..... | 1.24 | 11.2 | 11.2 | 17.9 | ..... |
| Mar. 13, 1897 | 0.55 | 0 | 0.92 | 0.04 | ..... | 18.6 | 23.9 | ..... |
| Mar. 14, 1897 | 0.98 | 0 | ..... | 1.15 | ..... | 23.9 | 26.6 | 25.6 |
| Apr. 4, 1897 | 0.35 | .35 | ..... | 0.57 | 17.7 | 17.7 | 17.7 | ..... |
| Apr. 5, 1897 | 1.45 | 0 | 1.52 | 1.80 | ..... | 19.4 | 28.4 | 29.3 |
| Sept. 1, 1898 | 1.84 | 0 | ..... | 2.17 | 15.3 | 15.3 | 29.3 | [3] 20.0 |
| Sept. 2, 1898 | 1.99 | 1.55 | 1.09 | 2.94 | [3] 28.4 | 28.4 | 29.0 | 29.0 |

[1] Estimated rise based on theoretical estimate from rainfall reported at 8 a. m. of the previous day.

[2] A 36-foot stage was predicted on July 8, 1896, and seems to have been conservative. Shortage probably due to extremely erratic distribution of rain.

[3] River rose to 29 feet in early morning of Sept. 2, 1898, fell to 28.4 at 8 a. m., and rose to 29 feet on the 3d.

TABLE XVI.—*Effect of rainfall over the watershed in two or more 24-hour periods on Savannah River stages at Augusta, Ga.*—Continued.

| Date. | Average rain. | Absorption, etc. | Plus 30 per cent last upper. | Average, upper section. | Initial stage. | Stage at 8 a. m. | Estimated stage. | Highest stage. |
|---|---|---|---|---|---|---|---|---|
| | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Feb. 5, 1899 | 0.66 | 0.25 | ..... | 0.77 | 14.5 | 14.5 | 18.8 | ..... |
| Feb. 6, 1899 | 0.80 | .25 | 0.71 | 1.12 | ..... | 20.8 | [1] 22.9 | ..... |
| Feb. 7, 1899 | 1.92 | 0 | 2.18 | 1.55 | ..... | 28.0 | [1] 32.1 | 31.0 |
| Feb. 10, 1900 | 0.71 | 0 | ..... | 0.61 | 8.4 | 8.4 | 14.4 | ..... |
| Feb. 11, 1900 | 0.87 | 0 | 1.05 | 0.91 | ..... | 19.5 | [1] 23.1 | ..... |
| Feb. 12, 1900 | 1.50 | .44 | 1.33 | 1.50 | ..... | 26.6 | [1] 28.5 | ..... |
| Feb. 13, 1900 | 1.84 | 0 | 2.16 | 2.16 | ..... | 28.5 | 32.7 | 32.7 |
| Apr. 18, 1900 | 0.89 | .50 | ..... | 0.95 | 9.0 | 9.0 | 12.3 | ..... |
| Apr. 19, 1900 | 1.72 | 0 | 1.86 | 1.17 | ..... | 22.2 | [1] 26.1 | ..... |
| Apr. 20, 1900 | 0.95 | .50 | 0.80 | 0.64 | ..... | 25.3 | 26.9 | ..... |
| Apr. 21, 1900 | 1.70 | .54 | 1.20 | 1.95 | ..... | 24.0 | 28.0 | 28.0 |
| May 19, 1901 | 0.89 | .75 | ..... | 0.93 | 8.4 | 8.4 | 9.6 | ..... |
| May 20, 1901 | 1.27 | .50 | 0.82 | 0.84 | ..... | 12.2 | [1] 16.6 | ..... |
| May 21, 1901 | 1.13 | .50 | 0.73 | 1.14 | ..... | 19.8 | [1] 21.7 | ..... |
| May 22, 1901 | 1.79 | .72 | 1.26 | 2.40 | ..... | 23.6 | [1] 27.7 | 27.7 |
| Sept. 17, 1901 | 1.53 | 1.00 | ..... | 2.23 | 9.0 | 9.0 | 13.5 | ..... |
| Sept. 18, 1901 | 2.99 | .77 | 2.59 | 2.78 | ..... | 23.4 | [1] 31.6 | 31.6 |
| Dec. 28, 1901 | 0.71 | 0 | ..... | 0.48 | 9.3 | 10.5 | 15.3 | ..... |
| Dec. 29, 1901 | [4] 1.76 | 0 | 1.90 | [4] 2.37 | ..... | 14.1 | 29.2 | 31.0 |
| Jan. 31, 1902 | 0.70 | .37 | ..... | 0.72 | 11.4 | 11.4 | 14.2 | ..... |
| Feb. 1, 1902 | 1.31 | 0 | 1.41 | 1.33 | ..... | 14.2 | 26.2 | ..... |
| Feb. 2, 1902 | 1.86 | 0 | 2.26 | 1.75 | ..... | 28.0 | [1] 32.7 | 32.6 |
| Mar. 16, 1902 | [4] 1.18 | 0 | ..... | 0.84 | 13.3 | 14.6 | 23.3 | ..... |
| Mar. 17, 1902 | 1.04 | 0 | 1.29 | 0.91 | ..... | 27.2 | [1] 28.4 | 27.5 |
| Mar. 21, 1903 | 0.73 | .50 | ..... | 0.75 | 11.6 | 11.6 | 13.6 | ..... |
| Mar. 22, 1903 | 0.98 | .25 | 0.80 | 1.00 | ..... | 16.5 | [1] 20.4 | ..... |
| Mar. 23, 1903 | 1.82 | .30 | 1.74 | 2.17 | ..... | 23.1 | 30.0 | ..... |
| Mar. 24, 1903 | ..... | ..... | ..... | ..... | ..... | 28.9 | ..... | 30.0 |
| Mar. 29, 1903 | 0.75 | .50 | ..... | 0.86 | 14.5 | 14.5 | 16.6 | ..... |
| Mar. 30, 1903 | 1.82 | .49 | 1.44 | 2.29 | ..... | 23.5 | [1] 27.6 | 27.6 |
| June 5, 1903 | 1.12 | .52 | ..... | 1.47 | 13.0 | 13.0 | 18.1 | ..... |
| June 6, 1903 | 1.07 | 0 | 1.35 | 1.23 | ..... | 18.1 | 27.2 | 27.3 |
| Aug. 8, 1904 | 2.84 | .99 | ..... | 3.41 | 8.3 | 14.0 | 24.0 | ..... |
| Aug. 9, 1904 | 0.59 | .59 | 0.58 | 0.62 | ..... | 23.2 | [1] 25.6 | 25.5 |
| Feb. 12, 1905 | 0.89 | 0 | ..... | 0.79 | 16.9 | 16.9 | 23.1 | ..... |
| Feb. 13, 1905 | 0.85 | 0 | 1.09 | 0.36 | ..... | 22.3 | 26.7 | 25.8 |
| Mar. 19, 1906 | 0.88 | .25 | ..... | 1.36 | 13.8 | 13.8 | 19.2 | ..... |
| Mar. 20, 1906 | 1.22 | 0 | 1.55 | 1.27 | ..... | 24.6 | [1] 28.9 | 28.6 |
| Feb. 10, 1908 | 0.80 | 0 | ..... | 0.86 | 11.0 | 11.0 | 17.8 | ..... |
| Feb. 11, 1908 | 1.01 | 0 | 1.27 | 0.82 | ..... | 21.0 | [1] 26.5 | 25.8 |
| Mar. 23, 1908 | 1.10 | 0 | ..... | 1.17 | 14.0 | 14.0 | 23.4 | ..... |
| Mar. 24, 1908 | 1.40 | 0 | 1.75 | 1.15 | ..... | 23.0 | 30.6 | 29.7 |
| Aug. 24, 1908 | 2.23 | .96 | ..... | 3.08 | 11.5 | 11.9 | 22.3 | ..... |
| Aug. 25, 1908 | 2.82 | 0 | 3.45 | 3.93 | ..... | 22.3 | 35.4 | ..... |
| Aug. 26, 1908 | 2.61 | 0 | 3.79 | 3.42 | ..... | 34.4 | 38.8 | 38.8 |
| Feb. 22, 1909 | 0.78 | 0 | ..... | 1.06 | 13.6 | 13.6 | 20.2 | ..... |
| Feb. 23, 1909 | 0.93 | 0 | 1.25 | 0.82 | ..... | 21.0 | [1] 27.1 | 26.4 |
| Mar. 12, 1909 | [5] 0.68 | 0 | ..... | 0.39 | 23.0 | 23.0 | 23.0 | ..... |
| Mar. 13, 1909 | 1.09 | 0 | ..... | 0.96 | ..... | 26.7 | [1] 26.7 | ..... |
| Mar. 14, 1909 | 0.64 | 0 | 0.93 | 0.79 | ..... | 26.7 | 27.6 | 28.0 |
| June 3, 1909 | 1.74 | .65 | ..... | 2.33 | 10.8 | 10.8 | 20.0 | ..... |
| June 4, 1909 | 1.89 | .89 | 1.50 | 2.12 | ..... | 23.5 | [1] 28.7 | 28.7 |
| Dec. 21, 1911 | 1.03 | .22 | ..... | 1.07 | 9.4 | 11.8 | 16.3 | ..... |
| Dec. 22, 1911 | [4] 2.80 | .63 | [4] 2.17 | 2.72 | ..... | 16.3 | 31.5 | 31.5 |
| Apr. 21, 1912 | 1.05 | 1.05 | ..... | 0.66 | 16.8 | 17.1 | 17.1 | ..... |
| Apr. 22, 1912 | [4] 1.24 | 0 | 1.24 | 0.74 | ..... | 17.5 | 26.2 | 26.5 |
| Jan. 24, 1913 | 0.46 | 0 | ..... | 0.66 | 9.6 | 9.6 | 13.5 | ..... |
| Jan. 25, 1913 | 1.15 | 0 | 1.35 | ..... | ..... | 19.2 | [1] 25.0 | 25.5 |
| Feb. 28, 1913 | 0.76 | 0 | ..... | 0.56 | 13.4 | 13.4 | 21.2 | ..... |
| Mar. 1, 1913 | 1.41 | 0 | 1.57 | ..... | ..... | 21.5 | 29.5 | 28.2 |
| Mar. 13, 1913 | 0.79 | 0 | ..... | 0.78 | 14.3 | 14.3 | 21.0 | ..... |
| Mar. 14, 1913 | 0.91 | 0 | 1.14 | 1.16 | ..... | 17.8 | 25.5 | ..... |
| Mar. 15, 1913 | [4] 2.71 | 0 | 3.06 | ..... | ..... | 29.3 | [1] 35.0 | 35.1 |

[1] Estimated rise based on theoretical estimate from rainfall reported at 8 a. m. of the previous day.
[4] Reports covered two dates but rain fell in 24 hours.
[5] Dropped on account of capacity of stream to carry off without a rise.
[6] No consideration given rains in upper section of watershed of Dec. 21, 1911, the two rains being distinct and about 36 hours apart.

## RIVER GAGE RELATIONS BETWEEN CARLTON, GA., AND CALHOUN FALLS, S. C., AND AUGUSTA, GA.

While average rainfall is the prime consideration in the predicting of river stages at Augusta, it has been found that when there are complications reference to the river gage readings at Carlton, Ga., on the Broad River, and Calhoun Falls, S. C., on the Savannah River, is frequently of great assistance. Before applying these readings to the problem, however, the forecaster must be reasonably sure the rainfall has had time to cause an approximately maximum rise at the substations named. From a study of the gage relation diagrams for individual rises, the following table has been prepared.

TABLE XVII.—*Relation of the mean of the river stages at Carlton and Calhoun Falls to the ultimate maximum stage at Augusta.*

| Average of river stages Carlton and Calhoun Falls. | 24 hours later, Augusta— | |
|---|---|---|
| | Will reach— | But not over— |
| *Feet.* | *Feet.* | *Feet.* |
| 5 | 18 | 22 |
| 6 | 20 | 25 |
| 7 | 21 | 27 |
| 8 | 22 | 28 |
| 9-10 | 25 | 32 |
| 11-12 | 26 | 33 |
| 13-14 | 28 | 34 |
| 15-16 | 29 | 34 |
| 17-18 | 30 | 35 |
| 19-20 | 31 | 36 |
| 21-22 | 32 | 37 |
| 23-24 | 33 | 37 |
| 25-26 | 34 | 38 |
| 27-28 | 37 | 39 |
| 29-30 | 38 | 40 |

## LATITUDE IN FORECASTING BEST SERVES PUBLIC INTERESTS.

It has been found by experience that the taking of latitude in stating a river forecast for Augusta is frequently desirable, since the information thus conveyed is more complete than it would be if a definite figure were named regardless of the uncertainties involved in the estimate.

When no more rain is indicated and the problem is clean-cut no latitude is necessary.

When no more rain is expected, but the problem involves uncertainties, a latitude of 1 or 2 feet may be taken. In predicting stages above 32 feet a 2-foot latitude should nearly always be taken.

When more rain is expected it is always advisable to take a latitude of 2 feet, as 26 to 28 feet or 30 to 32 feet.

## RELATION OF THE HOURLY RATE OF RISE TO THE ULTIMATE STAGE.

So much does the time of the beginning of the rise and the hourly rate of rise at stages under 20 feet depend upon the distance of the heaviest rainfall from Augusta, the rate of rainfall, and soil conditions, that reliable rules of relationship between the hourly rate of rise at such stages and the maximum stage likely to be reached are impossible to calculate. At times when the precipitation is heavy and continuous in that portion of the watershed immediately above Augusta, a night rise from a stage of 10 or 12 feet will reach 20 or 22 feet before it is possible

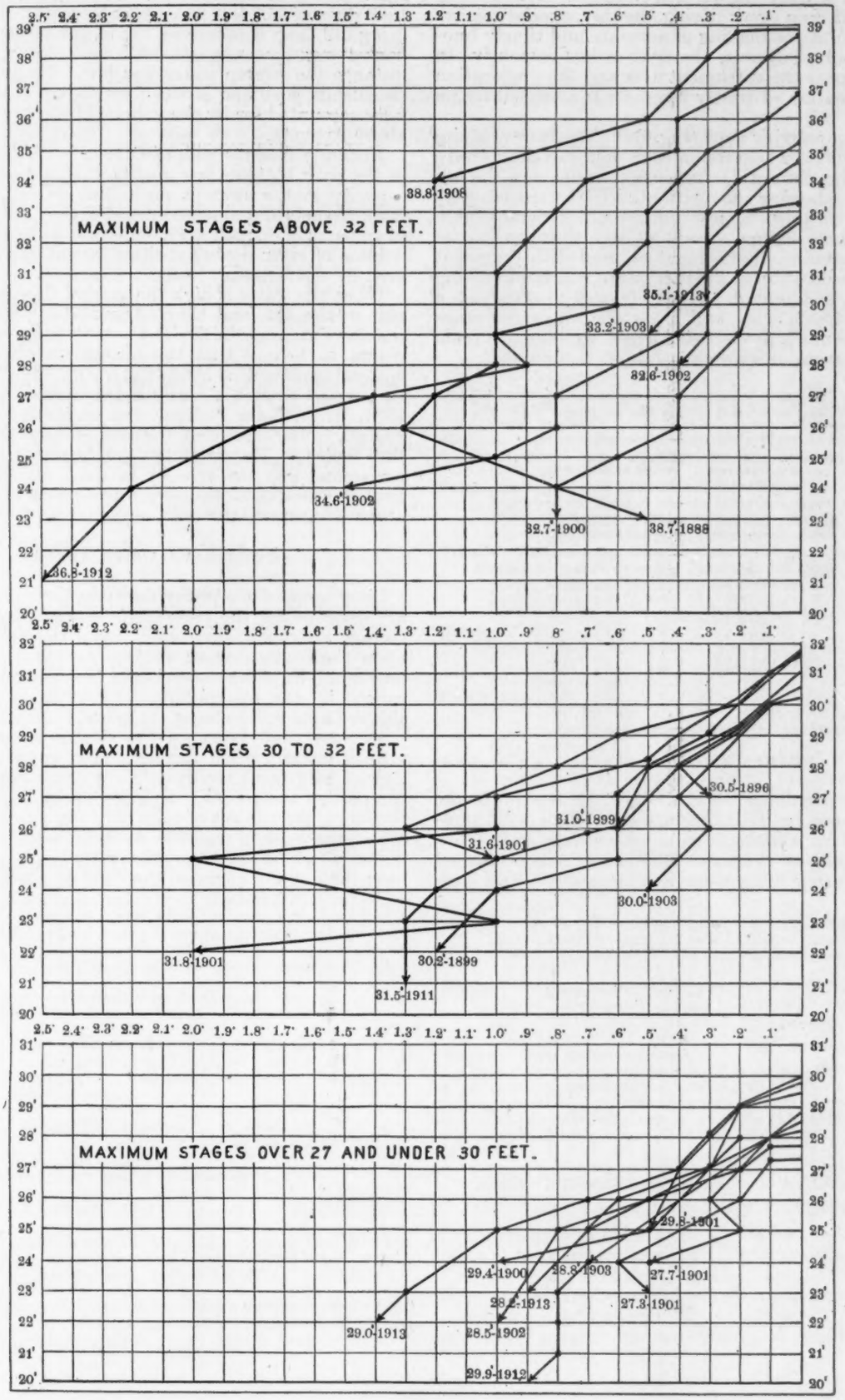


FIG. 4.—River forecast scheme. Diagram No. III. Rate of hourly rise in the Savannah River at Augusta, Ga., for all maximum stages between 27 and 40 feet.

to get reports from the rainfall stations. When these sudden rapid rises occur during the day, special reports greatly assist in the making of accurate and timely forecasts. Usually, however, the river is less responsive to the rainfall over the catchment area and the preparation and dissemination of timely forecasts is attended by no difficulty.

In an accompanying chart (Fig. 4) the hourly rates of rise for all freshets for which the information is available have been plotted. From this chart has been deduced the following table, showing the relation likely to exist between the rate of rise above 22 feet and the ultimate maximum stage. If these figures should at any time become of special importance, they should be used with judgment and due consideration of whether or not rain is still falling or more rain is expected. It may be well to state that a brisk downstream wind will lower the maximum stage sometimes as much as a foot and a half, while an upstream wind will increase it somewhat.

TABLE XVIII.—*Rise to be expected in the Savannah River at Augusta, Ga., for various rates of rise per hour.*

| Maximum stage expected to be between 25 and 30 feet. | | Maximum stage expected to be over 30 feet. | |
|---|---|---|---|
| Hourly rise. | Indicates further rise. | Hourly rise. | Indicates further rise. |
| *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 0.1 | 0.5 or less. | 0.1 | 1.0 or less. |
| 0.2 | 1.0 to 1.5 | 0.2 | 1.0 to 2.0 |
| 0.3 | 1.0 to 3.0 | 0.3 | 3.0 to 5.0 |
| 0.4 | 2.0 to 3.0 | 0.4 | 3.5 to 5.0 |
| 0.5 | 3.0 to 5.0 | 0.5 | 3.5 to 5.5 |
| 0.6 | 3.0 to 5.5 | 0.6 | 4.0 to 6.0 |
| 0.7 | 3.0 to 6.0 | 0.7 | 5.0 to 7.0 |
| 0.8 | 4.0 to 8.0 | 0.8 | 5.0 to 8.0 |
| | | 1.0 | 6.0 to 10.0 |
| | | 1.2 | 8.0 to 12.0 |
| | | 1.3 | 9.0 to 13.0 |

### SWAMPS BELOW AUGUSTA.

There is a popular belief that when the swamps in the Savannah basin below Augusta are surfeited with moisture the swamp water acts as an obstruction to the flow of the stream at Augusta and causes higher freshet stages than occur when there is a large unsatisfied storage capacity in the swamps. It has been said that the 1888 stage of 38.7 feet was higher by reason of the swamps being full than it otherwise would have been. The 1908 freshet was, however, one-tenth foot higher, and in that instance the swamp water was low. In assigning these two floods positions in the forecast scheme, both seem fully accounted for by the volume of water received from above Augusta.

Moderate freshets will, of course, inundate farm lands in the river bottoms less readily when a depleted storage capacity in the swamps must first be satisfied, but in large freshets the amount of water thus retained by the swamps is so small as compared with the immense volume of river flow that little benefit can be expected even by the farmers.

When the water is high the sudden slowing of the current in the flat land below Augusta undoubtedly raises the stage at Augusta to some extent, but there seems no reason to believe that the magnitude of this effect is noticeably influenced by the water contents of the swamps. In a report to Hon. Charles Estes, mayor of Augusta, in 1874, Mr. William Phillips, civil engineer, estimated the velocity of the current on the 52-foot drop in 6 miles from Bull Sluice to Hawks Gulley (in Augusta) as 19.50 feet per second and the velocity between Hawks Gully and Butlers Creek, a distance of 12.75 miles with a drop of about 6 inches to the mile, as only 1.75 feet per second.

### POWER DAMS ABOVE AUGUSTA.

Since none of the power dams on the Savannah River are designed for the permanent impounding of water in storage reservoirs, their effect upon the stream flow and upon the freshet stages at Augusta may be considered negligible, with the exception of the diurnal fluctuations caused by the manipulations of water in the Augusta Power Canal when stages are below 10 feet.

Reports that dams up the stream have broken are always current when danger stages are reached or expected, and these reports always cause much alarm on the part of the people. Engineers who have been questioned on the subject of possible danger from this source are of the opinion that the washing away of one of the dams, which are submerged by the high water, would have little if any effect on the flood situation.

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## SECTION VI. WEATHER AND DATA FOR THE MONTH.

### THE WEATHER OF THE MONTH.

By P. C. DAY, Climatologist and Chief of Division.

*Pressure.*—The distribution of the mean atmospheric pressure over the United States and Canada, and the prevailing direction of the winds, are graphically shown on Chart VII, while the average values for the month at the several stations, with the departures from the normal, are shown in Tables I and III.

For the month as a whole barometric pressure was low over nearly all portions of the country, but especially so in the northern districts from the Lake region westward to the Pacific, and over the Canadian Northwest. The only portion of the country where the pressure averaged above normal was in the southern Rocky Mountain and southern Plateau regions, where comparatively high pressure continued during much of the first half of the month. Pressure was unusually high over the northeastern districts about the 14th, and again from the 27th to 29th, but otherwise it was not unusually high at any time during the month, nor was it especially low, except about the 3d and 4th along the Atlantic Coast, again about the 9th and 12th over the Lake region and New England, and about the 21st and 25th in New England, the month closing with low pressure and a storm of considerable severity over the upper Ohio Valley and Lower Lake region.

The distribution of the highs and lows was very generally favorable for the occurrence of southerly winds at frequent intervals over much of the country, and they were the prevalent winds during the month to westward of the Rocky Mountains, as well as over the middle Plains region, Ohio Valley, and to the southward.

*Temperature.*—The month opened with temperatures moderately low in southern districts, while decidedly cold weather was prevalent in northern New York and in New England, where temperatures were from 10° to 20° below zero. At the same time temperatures above the average prevailed in the Rocky Mountain region and the Northwest. During the following few days unseasonably warm weather overspread the eastern districts, while in its wake temperature conditions returned to about normal, with moderately cold weather in southern districts and frosts over much of Florida. Warmer weather followed, and by the end of the first decade it had extended to all eastern districts.

At the beginning of the second decade colder weather advanced from the Northwest, the fall in temperature being quite marked from the 11th to 12th in the upper Mississippi and middle Missouri valleys. By the 13th the cold area had advanced to New York and New England, with minimum temperatures as much as 20° below zero, and during the following day the line of zero temperature had extended to southern New Jersey and southeastern Pennsylvania, with a still further fall to 30° below in northern New York. During the passage of this cold area over northern districts moderate weather continued in southern districts, and temperature rose to near normal in the central and western sections. By the 15th the cold wave over the northeast had moved into the Atlantic, and temperatures near or above the seasonal average prevailed during the remainder of the month over nearly all districts, the last decade being especially warm over the central and eastern districts, except that near the end of the month colder weather had overspread portions of the northern sections.

The month as a whole was among the warmest of its name in the past 40 years, the average temperature exceeding the normal in all portions, save in northern New York and portions of New England, and over extreme southern Florida, where the averages were slightly below normal. Over the interior portions of the country and in the far northwest the excess ranged from 9° to 12° per day, and in some portions of the above-named regions the persistence of uniformly warm weather was without parallel in any previous January of record. January was the third consecutive month with temperatures abnormally high over practically all portions of the country to eastward of the Rocky Mountains, while two of the months had temperatures in excess of the normal to the westward.

The line of freezing temperature for January scarcely reached the Gulf coast, while zero temperatures were not recorded in the central districts south of northern Nebraska, northern Iowa, and southern Wisconsin. No unusual extremes of temperature occurred, although near the first of the month maximum temperatures were as high as previously reported in January at a few points in the far Northwest, and also near the close at a few points in the Middle Atlantic States.

*Precipitation.*—The geographical distribution of the precipitation during the month is illustrated on Chart V, the notable features of which are the heavy falls over the Pacific coast States, especially in southern California, and in portions of the western slopes of the Rocky Mountains in Colorado and adjoining States.

The precipitation along the eastern slope of the Rocky Mountains and over the western portions of the Great Plains region was exceedingly light, but to the eastward there was a very general increase, the monthly totals near the Atlantic Coast averaging from 2 to 4 inches or slightly more. The amounts, however, were generally less than the average, the deficiencies being especially marked in the Gulf States and portions of the Ohio and middle Mississippi Valleys. To the westward of the Rocky Mountains the precipitation was generally above the normal, the excess amounting to 10 inches or more at points along the immediate coasts of southern California, northwestern Oregon, and southwestern Washington.

*Snowfall.*—Some heavy falls of snow occurred in the lower Lake region and in portions of the Appalachian Mountain districts, but elsewhere to eastward of the Rocky Mountains the amounts as a rule were unusually light for a midwinter month. In the far western mountains, heavy falls appear to have occurred in portions of California, Utah, and Oregon, and moderate amounts were rather general on the western slopes of the Rockies. The supply of snow in the mountains appears ample for irrigation and other purposes in California, portions of Utah and Colorado, and portions of the States farther

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north. In Arizona and New Mexico, however, the stored supply of snow appears inadequate.

## GENERAL SUMMARY.

The continuation for the third consecutive month of unusually high temperatures over nearly all the districts from the Rocky Mountains eastward, the general absence of any appreciable snowfall over much of the great wheat-growing area, the deficiency in precipitation over the Gulf States, and the excess in the far West were the important features of the weather for the month of January, 1914.

The large number of warm, sunny days in the interior and southern portions of the country and the general absence of frost in the ground permitted of almost uninterrupted outdoor work, while the absence of any appreciable snow covering permitted the continued grazing of stock in many localities. The heavy rains and snows in California and portions of adjoining States have been very beneficial, and the outlook for the next season's water supply has been greatly improved.

*Average accumulated departures for January, 1914.*

| Districts. | Temperature. | | | Precipitation. | | | Cloudiness. | | Relative humidity. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | General means for the current month. | Departures for the current month. | Accumulated departures since Jan. 1. | General means for the current month. | Departures for the current month. | Accumulated departures since Jan. 1. | General means for the current month. | Departure from the normal. | General means for the current month. | Departure from the normal. |
| | | | | | | | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* |
| New England | 24.4 | − 0.1 | .... | 3.14 | −0.30 | .... | 71 | +12 | 77 | + 1 |
| Middle Atlantic | 34.7 | + 3.4 | .... | 3.26 | 0.00 | .... | 65 | + 7 | 75 | − 1 |
| South Atlantic | 48.7 | + 3.7 | .... | 2.43 | −1.50 | .... | 46 | − 7 | 72 | − 5 |
| Florida Peninsula | 59.3 | − 0.2 | .... | 3.60 | +0.90 | .... | 50 | + 2 | 80 | − 1 |
| East Gulf | 50.5 | + 3.1 | .... | 1.91 | −3.10 | .... | 44 | −13 | 72 | − 6 |
| West Gulf | 52.5 | + 6.3 | .... | 0.72 | −2.20 | .... | 41 | −12 | 68 | − 8 |
| Ohio Valley and Tennessee | 38.4 | + 5.2 | .... | 2.24 | −1.60 | .... | 72 | + 8 | 77 | 0 |
| Lower Lakes | 27.7 | + 3.4 | .... | 2.65 | 0.00 | .... | 81 | + 7 | 82 | + 1 |
| Upper Lakes | 24.3 | + 6.1 | .... | 2.39 | 0.40 | .... | 88 | +19 | 84 | + 1 |
| North Dakota | 14.8 | + 9.8 | .... | 0.64 | 0.00 | .... | 62 | +13 | 82 | + 2 |
| Upper Mississippi Valley | 31.1 | + 9.6 | .... | 1.28 | −0.50 | .... | 74 | +20 | 80 | + 2 |
| Missouri Valley | 31.8 | +10.7 | .... | 0.50 | −0.60 | .... | 56 | + 6 | 76 | + 1 |
| Northern slope | 28.3 | + 9.3 | .... | 0.49 | −0.40 | .... | 61 | +10 | 68 | − 2 |
| Middle slope | 39.2 | +10.1 | .... | 0.10 | −0.60 | .... | 40 | − 1 | 64 | − 3 |
| Southern slope | 48.5 | + 8.3 | .... | 0.04 | −0.90 | .... | 34 | −10 | 54 | −12 |
| Southern Plateau | 45.2 | + 3.4 | .... | 0.59 | −0.30 | .... | 41 | + 7 | 59 | + 9 |
| Middle Plateau | 28.8 | + 4.7 | .... | 2.52 | +1.40 | .... | 61 | +10 | 75 | + 5 |
| Northern Plateau | 35.7 | + 8.6 | .... | 2.22 | +0.50 | .... | 80 | +13 | 69 | −11 |
| North Pacific | 43.5 | + 4.0 | .... | 12.64 | +5.90 | .... | 89 | +14 | 88 | + 3 |
| Middle Pacific | 48.8 | + 1.5 | .... | 8.16 | +3.50 | .... | 65 | + 9 | 84 | + 3 |
| South Pacific | 53.9 | + 3.0 | .... | 8.48 | +5.70 | .... | 60 | +15 | 75 | + 3 |

*Maximum wind velocities during January, 1914.*

| Stations. | Date. | Velocity. | Direction. | Stations. | Date. | Velocity. | Direction. |
|---|---|---|---|---|---|---|---|
| Block Island, R. I. | 3 | 60 | ne. | Buffalo, N. Y. | 12 | 74 | sw. |
| Do. | 4 | 60 | ne. | Do. | 23 | 50 | sw. |
| Do. | 10 | 55 | w. | Do. | 27 | 52 | sw. |
| Do. | 12 | 67 | w. | Do. | 29 | 54 | sw. |
| Do. | 13 | 80 | nw. | Do. | 31 | 92 | sw. |
| Do. | 21 | 60 | nw. | Burlington, Vt. | 27 | 52 | s. |
| Do. | 22 | 60 | nw. | Do. | 29 | 50 | s. |
| Boston, Mass. | 12 | 51 | nw. | Canton, N. Y. | 31 | 53 | sw. |
| Buffalo, N. Y. | 6 | 56 | sw. | Cheyenne, Wyo. | 1 | 50 | w. |
| Do. | 11 | 64 | sw. | Do. | 6 | 50 | w. |

*Maximum wind velocities during January, 1914*—Continued.

| Stations. | Date. | Velocity. | Direction. | Stations. | Date. | Velocity. | Direction. |
|---|---|---|---|---|---|---|---|
| Cheyenne, Wyo. | 10 | 50 | w. | North Head, Wash. | 6 | 80 | se. |
| Do. | 13 | 52 | w. | Do. | 10 | 64 | se. |
| Do. | 15 | 52 | w. | Do. | 15 | 80 | se. |
| Do. | 21 | 52 | w. | Do. | 16 | 62 | se. |
| Do. | 22 | 52 | w. | Do. | 17 | 92 | se. |
| Do. | 23 | 50 | w. | Do. | 18 | 60 | s. |
| Do. | 24 | 62 | w. | Do. | 21 | 56 | sw. |
| Do. | 25 | 70 | w. | Do. | 22 | 50 | sw. |
| Do. | 29 | 50 | w. | Do. | 25 | 88 | s. |
| Cleveland, Ohio. | 12 | 60 | w. | Do. | 26 | 72 | s. |
| Columbus, Ohio. | 12 | 52 | nw. | Do. | 27 | 60 | nw. |
| El Paso, Tex. | 28 | 50 | sw. | Do. | 29 | 68 | s. |
| Eureka, Cal. | 11 | 50 | se. | Pittsburgh, Pa. | 12 | 50 | nw. |
| Do. | 25 | 59 | sw. | Do. | 31 | 51 | sw. |
| Grand Haven, Mich. | 11 | 50 | nw. | Point Reyes Light, Cal. | 1 | 66 | s. |
| Helena, Mont. | 1 | 62 | sw. | Do. | 2 | 68 | s. |
| Independence, Cal. | 25 | 50 | sw. | Do. | 8 | 69 | nw. |
| Lander, Wyo. | 25 | 54 | sw. | Do. | 11 | 53 | s. |
| Modena, Utah | 25 | 54 | s. | Do. | 12 | 67 | s. |
| Do. | 26 | 52 | sw. | Do. | 13 | 65 | s. |
| Mount Tamalpais, Cal. | 2 | 52 | sw. | Do. | 14 | 64 | s. |
| Do. | 8 | 50 | nw. | Do. | 16 | 84 | s. |
| Do. | 17 | 57 | sw. | Do. | 17 | 66 | s. |
| Do. | 18 | 50 | sw. | Do. | 18 | 51 | s. |
| Do. | 21 | 52 | s. | Do. | 21 | 56 | s. |
| Do. | 24 | 53 | sw. | Do. | 23 | 64 | s. |
| Do. | 25 | 66 | sw. | Do. | 24 | 70 | s. |
| Do. | 27 | 60 | nw. | Do. | 25 | 62 | sw. |
| Do. | 28 | 70 | nw. | Do. | 27 | 64 | nw. |
| Mount Weather, Va. | 3 | 58 | e. | Providence, R. I. | 10 | 62 | nw. |
| Do. | 7 | 56 | nw. | Do. | 12 | 74 | nw. |
| Do. | 10 | 66 | nw. | Do. | 13 | 64 | nw. |
| Do. | 11 | 54 | nw. | Do. | 25 | 50 | nw. |
| Do. | 12 | 72 | nw. | Richmond, Va. | 31 | 52 | sw. |
| Do. | 17 | 60 | nw. | St. Paul, Minn. | 11 | 51 | nw. |
| Do. | 18 | 54 | nw. | Seattle, Wash. | 7 | 52 | s. |
| Do. | 21 | 66 | nw. | Do. | 26 | 57 | sw. |
| Do. | 24 | 56 | nw. | Sheridan, Wyo. | 1 | 52 | nw. |
| Do. | 25 | 52 | nw. | Sioux City, Iowa. | 28 | 52 | nw. |
| Nantucket, Mass. | 1 | 54 | ne. | Tatoosh Island, Wash. | 1 | 58 | se. |
| Do. | 4 | 59 | ne. | Do. | 2 | 84 | s. |
| Do. | 12 | 50 | w. | Do. | 3 | 64 | s. |
| Do. | 13 | 55 | w. | Do. | 4 | 72 | s. |
| New York, N. Y. | 10 | 69 | nw. | Do. | 5 | 62 | s. |
| Do. | 12 | 76 | nw. | Do. | 16 | 52 | s. |
| Do. | 13 | 71 | nw. | Do. | 17 | 50 | e. |
| Do. | 18 | 52 | nw. | Do. | 18 | 66 | sw. |
| Do. | 21 | 62 | nw. | Do. | 19 | 50 | sw. |
| Do. | 24 | 56 | s. | Do. | 25 | 60 | s. |
| Do. | 25 | 64 | nw. | Do. | 26 | 52 | sw. |
| Do. | 31 | 52 | s. | Do. | 27 | 50 | w. |
| Norfolk, Va. | 12 | 52 | w. | Do. | 29 | 70 | s. |
| Do. | 21 | 50 | w. | Do. | 31 | 52 | w. |
| Do. | 25 | 51 | w. | Tonopah, Nev. | 17 | 50 | se. |
| Do. | 31 | 50 | sw. | Trenton, N. J. | 3 | 56 | ne. |
| North Head, Wash. | 1 | 52 | s. | Do. | 12 | 60 | w. |
| Do. | 2 | 80 | se. | Valentine, Nebr. | 1 | 50 | nw. |
| Do. | 3 | 72 | se. | | | | |
| Do. | 4 | 76 | se. | | | | |
| Do. | 5 | 78 | se. | | | | |

## MEAN LAKE LEVELS DURING JANUARY, 1914.

The following data are as reported monthly by the United States Lake Survey:

| | Lake Superior. | Lakes Michigan and Huron. | Lake Erie. | Lake Ontario. |
|---|---|---|---|---|
| Mean level during January, 1914: | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Above mean sea level at New York | 602.38 | 580.09 | 572.06 | 245.60 |
| Above or below— | | | | |
| Mean stage of December, 1913 | −0.36 | −0.26 | −0.08 | −0.31 |
| Mean stage of January, 1913 | +0.49 | 0 | −0.17 | −0.91 |
| Average stage for January, last 10 years | +0.34 | +0.03 | +0.32 | +0.01 |
| Highest recorded stage | −0.40 | −2.58 | −1.49 | −2.00 |
| Lowest recorded stage | +1.50 | +1.01 | +1.10 | +1.80 |
| Probable change during February | −0.2 | 0 | −0.1 | +0.1 |

## CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures with dates of occurrence; the stations reporting the greatest and least total precipitation, and other data, as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

*Summary of temperature and precipitation, by sections, January, 1914.*

| Section. | Temperature—in degrees Fahrenheit. | | | | | | | | Precipitation—in inches and hundredths. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Section average. | Departure from the normal. | Monthly extremes. | | | | | | Section average. | Departure from the normal. | Greatest monthly. | | Least monthly. | |
| | | | Station. | Highest. | Date. | Station. | Lowest. | Date. | | | Station. | Amount. | Station. | Amount. |
| Alabama | 48.0 | + 2.6 | Evergreen | 82 | 29 | Hamilton | 16 | 12 | 2.19 | −2.43 | Mentone | 5.40 | Daphne | 0.62 |
| Arizona | 46.8 | + 3.0 | Tucson (2) | 84 | 7 | Fort Valley | −13 | 29 | 0.97 | −0.23 | Thomas | 6.83 | Thatcher | T. |
| Arkansas | 46.6 | + 6.4 | Camden | 82 | 19 | Pond | 7 | 31 | 1.57 | −2.20 | Hardy | 3.71 | Eldorado | T. |
| California | 46.9 | + 1.1 | Riverside | 87 | 6 | Tamarack | −16 | 28 | 13.09 | +7.68 | Helen Mine | 43.68 | Bagdad | 0.00 |
| Colorado | 26.6 | + 2.1 | Canon City | 74 | 7 | 2 stations | −35 | 11† | 1.69 | +0.47 | Rico | 9.81 | 6 stations | 0.00 |
| Florida | 58.1 | + 0.2 | Fort Lauderdale | 88 | 10 | Garniers (near) | 21 | 7 | 4.22 | +1.61 | New Smyrna | 7.81 | Avon Park | 0.52 |
| Georgia | 47.2 | + 1.0 | Bainbridge | 84 | 29 | Mineral Bluff | 14 | 14 | 2.38 | −1.43 | Quitman | 5.85 | Carlton | 1.31 |
| Hawaii, [Dec., 1913] | 69.6 | ..... | Mahukona | 97 | 7 | Humuula | 41 | 14 | 5.73 | ..... | Hakalau | 29.45 | 3 stations | 0.00 |
| Idaho | 30.4 | + 4.8 | Culdesac | 62 | 17 | Blackfoot Dam | −27 | 12 | 2.90 | +0.63 | Burke | 8.37 | Grandview | 0.22 |
| Illinois | 34.0 | + 7.3 | Golconda | 72 | 29 | Dakota | − 3 | 12 | 1.93 | −0.46 | Chester | 3.12 | Morrison | 0.76 |
| Indiana | 34.9 | + 5.8 | Rome | 71 | 29 | Hammond | 3 | 12 | 2.26 | −0.79 | Salamonia | 3.49 | Collegeville | 0.53 |
| Iowa | 27.8 | + 9.9 | Keokuk | 64 | 28 | 2 stations | −10 | 12 | 0.88 | −0.17 | Fort Madison | 2.34 | Pacific Junction | 0.27 |
| Kansas | 37.8 | + 7.9 | Liberal | 75 | 26 | Irene | 0 | 11 | 0.17 | −0.58 | Columbus | 1.42 | 5 stations | 0.00 |
| Kentucky | 39.4 | + 4.0 | 3 stations | 76 | 28† | Farmers | 5 | 13 | 2.29 | −1.93 | Alpha | 3.45 | Leitchfield | 1.41 |
| Louisiana | 52.2 | + 2.9 | Donaldsonville | 92 | 27 | Grand Cane | 16 | 6† | 1.05 | −2.98 | Burrwood | 3.03 | Jeanerette | 0.00 |
| Maryland and Delaware | 36.1 | + 3.4 | Westernport | 76 | 29 | Deer Park | −14 | 14 | 3.84 | +0.82 | Fallston | 6.07 | Westernport | 1.71 |
| Michigan | 25.1 | + 4.7 | Lansing | 63 | 28 | Humboldt | −30 | 25 | 2.55 | +0.53 | Allegan | 5.96 | Charlevoix | 0.90 |
| Minnesota | 16.9 | + 9.0 | Winnebago | 57 | 15 | 2 stations | −38 | 25 | 0.81 | +0.03 | Caledonia | 2.42 | Angus | 0.28 |
| Mississippi | 49.8 | + 3.2 | Rosedale | 81 | 19 | Tupelo | 20 | 12† | 1.07 | −3.69 | Shubuta | 1.74 | Holly Bluff | 0.27 |
| Missouri | 38.1 | + 6.9 | Hollister | 78 | 28 | Dean | − 1 | 31 | 1.42 | −0.92 | Doniphan | 3.47 | Liberty | 0.05 |
| Montana | 26.3 | + 8.2 | Ingomar | 69 | 13 | Babb | −41 | 26 | 0.75 | −0.27 | Haugan | 5.58 | 3 stations | T. |
| Nebraska | 31.8 | +10.1 | Culbertson | 72 | 26 | Curly | − 9 | 11 | 0.23 | −0.33 | Madison | 1.10 | .....do | 0.00 |
| Nevada | 34.2 | + 5.3 | Logan | 87 | 1 | Tecoma | −25 | 11 | 3.06 | +1.62 | Marlette Lake | 15.86 | San Jacinto | 0.14 |
| New England | 21.1 | − 0.4 | 2 stations | 63 | 30 | Bloomfield, Vt | −44 | 14 | 2.93 | −0.72 | New Haven, Conn | 5.58 | Cornwall, Vt | 1.16 |
| New Jersey | 31.9 | + 1.9 | Tuckerton | 73 | 30 | Culvers Lake | −18 | 14 | 3.85 | 0.00 | Newark | 6.15 | Mahwah | 1.95 |
| New Mexico | 38.6 | + 3.4 | Lakewood | 85 | 23 | Dulce | −27 | 29 | 0.24 | −0.27 | Dulce | 2.30 | 27 stations | 0.00 |
| New York | 22.6 | + 0.3 | Allegany | 65 | 29 | 2 stations | −43 | 14 | 2.65 | −0.23 | Bedford | 7.28 | 2 stations | 0.90 |
| North Carolina | 43.5 | + 3.0 | Newbern | 82 | 30 | .....do | 9 | 12† | 2.62 | −1.08 | Highlands | 4.53 | Belhaven | 0.71 |
| North Dakota | 14.8 | + 9.8 | Hettinger | 62 | 16† | Willow City | −38 | 24 | 0.50 | +0.01 | Walhalla | 1.80 | Orange | 0.00 |
| Ohio | 33.4 | + 5.2 | 2 stations | 75 | 28† | Garrettsville | −17 | 14 | 2.30 | −0.62 | North Royalton | 3.95 | Kenton | 1.00 |
| Oklahoma | 45.0 | + 6.4 | Erick | 87 | 25 | 3 stations | 11 | 30 | 0.39 | −0.87 | Webbers Falls | 3.50 | 20 stations | 0.00 |
| Oregon | 38.5 | + 4.9 | Hermiston | 72 | 21 | Austin | − 6 | 10 | 8.14 | +3.74 | Glenora | 42.80 | Diamond | 0.58 |
| Pennsylvania | 30.2 | + 2.1 | Irwin | 81 | 29 | Lawrenceville | −27 | 14 | 3.37 | +0.14 | Lock Haven | 5.77 | Montrose | 1.40 |
| Porto Rico | 73.2 | + 0.1 | 3 stations | 92 | 2† | Cayey | 44 | 19 | 2.38 | −1.32 | Cavite Dam | 5.70 | Guanica Centrale | 0.44 |
| South Carolina | 46.7 | + 1.3 | Walterboro | 81 | 29 | Meriwether | 18 | 14 | 2.66 | −0.76 | Georgetown | 5.05 | Liberty | 1.11 |
| South Dakota | 25.3 | + 9.0 | Hermosa | 72 | 7 | Eureka | −23 | 12 | 0.33 | −0.10 | Hardy Ranger Sta | 1.79 | 6 stations | T. |
| Tennessee | 42.5 | + 4.1 | Johnson City | 77 | 28† | Crossville | 8 | 12 | 2.10 | −2.36 | Erasmus | 5.36 | Bolivar | 0.65 |
| Texas | 53.3 | + 5.3 | Fort McIntosh | 98 | 18 | Romero | 12 | 13 | 0.35 | −1.15 | Valley Junction | 2.50 | 32 stations | 0.00 |
| Utah | 28.5 | + 1.8 | Springdale | 71 | 8 | Woodside | −33 | 10 | 2.61 | +1.28 | Park City | 7.60 | Midlake | 0.09 |
| Virginia | 39.4 | + 4.2 | Ivor | 76 | 30 | 2 stations | − 1 | 13 | 3.23 | +0.10 | Mountain Lake | 6.20 | Woodstock | 1.64 |
| Washington | 36.9 | + 5.8 | Walla Walla | 70 | 6 | .....do | − 8 | 24† | 8.65 | +3.56 | Duckabush | 40.00 | Hanford | 1.12 |
| West Virginia | 35.8 | + 3.5 | 2 stations | 83 | 29 | Bayard | −11 | 14 | 3.18 | −0.73 | Bayard | 5.65 | Parkersburg | 1.55 |
| Wisconsin | 22.8 | + 8.6 | Milwaukee | 56 | 29 | Solon Springs | −33 | 25 | 1.16 | −0.17 | Rest Lake | 2.52 | Valley Junction | 0.40 |
| Wyoming | 24.4 | + 4.0 | Wheatland | 69 | 18 | Snake River, Y. N. P | −40 | 12 | 1.09 | +0.19 | Snake River, Y. N. P | 10.49 | 3 stations | T. |

† Other dates also.

## DESCRIPTION OF TABLES AND CHARTS.

Table I gives the data ordinarily needed for climatological studies for about 158 Weather Bureau stations making simultaneous observations at 8 a. m. and 8 p. m., seventy-fifth meridian time daily, and for about 41 others making only one observation. The altitudes of the instruments above ground are also given.

Table II gives a record of precipitation the intensity of which at some period of the storm's continuance equaled or exceeded the following rates:

| Duration (minutes) | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rates per hour (inches) | 3.00 | 1.80 | 1.40 | 1.20 | 1.08 | 1.00 | 0.94 | 0.90 | 0.87 | 0.84 | 0.80 |

In cases where no storm of sufficient intensity to entitle it to a place in the full table has occurred, the greatest precipitation of any single storm has been given, also the greatest hourly fall during that storm.

Table III gives, for about 30 stations of the Canadian Meteorological Service, the means of pressure and temperature, total precipitation and depth of snowfall, and the respective departures from normal values, except in the case of snowfall.

Chart I.—Hydrographs for several of the principal rivers of the United States.

Chart II.—Tracks of centers of high areas; and

Chart III.—Tracks of centers of low areas. The roman numerals show the chronological order of the centers. The figures within the circles show the days of the month; the letters *a* and *p* indicate, respectively, the observations at 8 a. m. and 8 p. m., seventy-fifth meridian time. Within each circle is also given (Chart II) the last three figures of the highest barometric reading and (Chart III) the lowest reading reported at or near the center at that time, and in both cases as reduced to sea level and standard gravity.

Chart IV.—Total precipitation. The scale of shades showing the depth is given on the chart. Where the monthly amounts are too small to justify shading, and

over sections of the country where stations are too widely separated or the topography is too diversified to warrant reasonable accuracy in shading, the actual depths are given for a limited number of representative stations. Amounts less than 0.005 inch are indicated by the letter T, and no precipitation by 0.

Chart V.—Percentage of clear sky between sunrise and sunset. The average cloudiness at each Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the observed cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are the basis of this chart. The chart does not relate to the nighttime.

Chart VI.—Isobars and isotherms at sea level and prevailing wind directions. The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of the REVIEW for January, 1902. The pressures have also been reduced to the mean of the 24 hours by the application of a suitable correction to the mean of the 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. observations, respectively, at stations taking but a single observation. The diurnal corrections so applied will be found in the Annual Report of the Chief of the Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The isotherms on the sea-level plane have been constructed by means of the data summarized in chapter 8 of volume 2 of the annual report just mentioned. The correction $t_o - t$, or temperature on the sea-level plane minus the station temperature as given by Table 48 of that report, is added to the observed surface temperature to obtain the adopted sea-level temperature.

The prevailing wind directions are determined from hourly observations at the great majority of the stations; a few stations having no self-recording wind direction apparatus determine the prevailing direction from the daily or twice-daily observations only.

Chart VII.—Total snowfall. This is based on the reports from regular and cooperative observers and shows the depth in inches and tenths of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given.

Chart VIII.—Depth of snow on ground at end of the month, expressed in inches and tenths.

Charts VII and VIII are published only when the general snow cover is sufficiently extensive to justify their preparation.

TABLE I.—*Climatological data for United States Weather Bureau stations, January, 1914.*

| Districts and stations. | Elevation of instruments. | | | Pressure in inches. | | | Temperature of the air, in degrees Fahrenheit. | | | | | | | | Mean wet thermometer. | Mean temperature of the dew point. | Mean relative humidity, per cent. | Precipitation, inches. | | | Wind. | | | | | Clear days. | Partly cloudy days. | Cloudy days. | Average cloudiness, tenths. | Total snowfall. | Snow on ground at end of month. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Barometer above sea level, feet. | Thermometer above ground. | Anemometer above ground. | Station, reduced to mean of 24 hours. | Sea level, reduced to mean of 24 hours. | Departure from normal. | Mean max.+mean min.÷2. | Departure from normal. | Maximum. | Date. | Mean maximum. | Minimum. | Date. | Mean minimum. | Greatest daily range. | | | | Total. | Departure from normal. | Days with 0.01 or more. | Total movement, miles. | Prevailing direction. | Maximum velocity. Miles per hour. | Maximum velocity. Direction. | Maximum velocity. Date. | | | | | | |
| *New England.* | | | | | | | **24.4** | **— 0.1** | | | | | | | | | **77** | **3.14** | **— 0.3** | | | | | | | | | **7.1** | | |
| Eastport | 76 | 67 | 85 | 29.80 | 29.89 | — .11 | 19.0 | — 1.1 | 49 | 30 | 27 | —16 | 14 | 10 | 45 | 17 | 14 | 79 | 4.18 | + 0.3 | 16 | 11,900 | n. | 48 | ne. | 12 | 6 | 7 | 18 | 7.3 | 20.9 | 2.0 |
| Greenville | 1,070 | 6 | .... | 28.69 | 29.92 | ..... | 9.7 | ..... | 40 | 30 | 20 | —25 | 14 | 0 | 41 | .... | .... | .... | 3.39 | ..... | 15 | .... | .... | .... | .... | .... | .... | .... | .... | 27.5 | 20.0 |
| Portland, Me. | 103 | 82 | 117 | 29.80 | 29.94 | — .11 | 20.5 | — 1.5 | 53 | 30 | 28 | —10 | 14 | 13 | 36 | 18 | 12 | 70 | 3.19 | — 0.6 | 17 | 8,077 | n. | 38 | nw. | 25 | 9 | 2 | 20 | 6.8 | 12.1 | 3.0 |
| Concord | 288 | 70 | 79 | 29.61 | 29.94 | — .11 | 19.0 | — 2.2 | 50 | 30 | 29 | —18 | 23 | 9 | 45 | .... | .... | .... | 2.75 | — 0.6 | 12 | 4,496 | nw. | 35 | nw. | 12 | 8 | 5 | 18 | 7.0 | 13.7 | 7.5 |
| Burlington | 404 | 11 | 48 | 29.49 | 29.96 | — .09 | 14.8 | — 1.5 | 44 | 30 | 24 | —26 | 14 | 5 | 45 | .... | .... | .... | 1.60 | — 0.2 | 12 | 10,283 | s. | 52 | s. | 27 | 7 | 4 | 20 | 7.3 | 7.0 | 2.7 |
| Northfield | 876 | 12 | 60 | 28.97 | 29.97 | — .08 | 12.2 | — 2.9 | 56 | 30 | 24 | —28 | 14 | 0 | 48 | 10 | 9 | 92 | 1.75 | — 0.7 | 15 | 5,562 | n. | 32 | s. | 29 | 8 | 2 | 21 | 7.1 | 13.9 | 13.3 |
| Boston | 125 | 115 | 188 | 29.77 | 29.91 | — .14 | 28.7 | + 1.7 | 63 | 30 | 36 | — 9 | 13 | 21 | 33 | 26 | 20 | 73 | 3.26 | — 0.6 | 10 | 9,628 | nw. | 51 | w. | 12 | 5 | 8 | 18 | 6.8 | 10.3 | .... |
| Nantucket | 12 | 14 | 90 | 29.87 | 29.88 | — .16 | 31.9 | — 0.2 | 51 | 31 | 38 | — 1 | 13 | 26 | 26 | 30 | 27 | 82 | 2.68 | — 0.7 | 14 | 14,963 | nw. | 59 | ne. | 4 | 5 | 6 | 20 | 7.6 | 0.5 | .... |
| Block Island | 26 | 11 | 46 | 29.87 | 29.90 | — .17 | 31.8 | + 0.4 | 54 | 31 | 38 | — 3 | 13 | 25 | 27 | 30 | 27 | 80 | 2.64 | — 1.2 | 10 | 18,105 | nw. | 80 | nw. | 13 | 6 | 5 | 20 | 7.5 | 0.6 | .... |
| Narragansett | .... | 9 | .... | ..... | ..... | ..... | 29.7 | + 1.3 | 60 | 30 | 38 | — 6 | 14 | 22 | 30 | .... | .... | .... | 3.23 | ..... | 10 | ..... | nw. | .... | ..... | ..... | 11 | 4 | 16 | .... | 3.0 | .... |
| Providence | 160 | 215 | 251 | 29.73 | 29.92 | — .14 | 28.7 | + 1.5 | 62 | 30 | 36 | — 5 | 14 | 21 | 34 | 26 | 22 | 76 | 3.56 | — 0.8 | 11 | 11,805 | nw. | 74 | nw. | 12 | 8 | 7 | 16 | 6.8 | 3.6 | .... |
| Hartford | 159 | 122 | 140 | 29.75 | 29.94 | — .13 | 26.8 | + 1.3 | 58 | 30 | 34 | — 8 | 14 | 20 | 30 | 24 | 19 | 73 | 3.38 | — 0.4 | 12 | 6,112 | nw. | 42 | nw. | 13 | 7 | 5 | 19 | 7.2 | 5.7 | .... |
| New Haven | 106 | 117 | 155 | 29.81 | 29.93 | — .15 | 29.3 | + 2.0 | 58 | 30 | 37 | — 5 | 13 | 22 | 30 | 26 | 19 | 68 | 5.58 | + 1.7 | 12 | 8,424 | n. | 48 | w. | 12 | 8 | 6 | 17 | 6.7 | 13.7 | .... |
| *Middle Atlantic States.* | | | | | | | **34.7** | **+ 3.4** | | | | | | | | | **75** | **3.26** | **0.0** | | | | | | | | | **6.5** | | |
| Albany | 97 | 102 | 115 | 29.85 | 29.96 | — .11 | 22.2 | — 0.3 | 50 | 28 | 30 | —15 | 14 | 14 | 32 | 20 | 16 | 78 | 1.91 | — 0.7 | 13 | 6,748 | s. | 35 | se. | 27 | 9 | 5 | 17 | 6.5 | 7.5 | T. |
| Binghamton | 871 | 10 | 69 | 28.97 | 29.93 | — .15 | 26.2 | + 3.1 | 51 | 29 | 34 | —10 | 14 | 19 | 28 | .... | .... | .... | 1.60 | — 0.4 | 11 | 4,874 | nw. | 31 | nw. | 12 | 1 | 4 | 26 | 8.8 | 4.9 | .... |
| New York | *314 | 414 | 454 | 29.58 | 29.94 | — .16 | 31.4 | + 1.2 | 58 | 30 | 39 | — 5 | 14 | 24 | 28 | 28 | 22 | 69 | 3.69 | — 0.1 | 13 | 14,982 | nw. | 76 | nw. | 12 | 6 | 6 | 19 | 7.4 | 1.2 | .... |
| Harrisburg | 374 | 94 | 104 | 29.55 | 29.96 | — .14 | 31.8 | + 3.1 | 55 | 28 | 38 | — 1 | 14 | 26 | 21 | 28 | 24 | 74 | 3.14 | + 0.3 | 12 | 6,246 | e. | 37 | ne. | 3 | 4 | 8 | 19 | 7.2 | 4.3 | .... |
| Philadelphia | 117 | 123 | 184 | 29.82 | 29.95 | — .16 | 35.4 | + 3.6 | 67 | 30 | 43 | 0 | 14 | 28 | 28 | 32 | 26 | 72 | 3.46 | 0.0 | 10 | 9,162 | nw. | 47 | ne. | 3 | 7 | 10 | 14 | 6.2 | 2.2 | .... |
| Reading | 325 | 81 | 98 | 29.59 | 29.95 | ..... | 31.2 | ..... | 56 | 28 | 38 | — 3 | 14 | 25 | 23 | 29 | 24 | 75 | 3.89 | ..... | 10 | 6,733 | nw. | 42 | nw. | 12 | 2 | 12 | 17 | 7.5 | 2.3 | .... |
| Scranton | 805 | 111 | 119 | 29.06 | 29.95 | — .14 | 28.2 | + 2.7 | 53 | 29 | 35 | —10 | 14 | 21 | 25 | 27 | 24 | 83 | 2.11 | — 0.7 | 14 | 5,689 | s. | 37 | w. | 10 | 1 | 7 | 23 | 8.5 | 6.3 | .... |
| Atlantic City | 52 | 37 | 48 | 29.89 | 29.95 | — .16 | 35.6 | + 3.1 | 64 | 28 | 42 | — 1 | 14 | 29 | 26 | 32 | 28 | 76 | 3.13 | — 0.3 | 10 | 7,608 | nw. | 38 | s. | 31 | 10 | 6 | 15 | 6.4 | T. | .... |
| Cape May | 17 | 13 | 49 | 29.94 | 29.96 | — .16 | 36.4 | + 2.3 | 64 | 28 | 43 | 3 | 14 | 30 | 26 | 34 | 32 | 86 | 4.32 | + 1.0 | 9 | 8,460 | nw. | 44 | ne. | 3 | 8 | 12 | 11 | 5.0 | 0.2 | .... |
| Trenton | 190 | 159 | 183 | 29.72 | 29.93 | ..... | 32.2 | ..... | 61 | 30 | 40 | — 4 | 14 | 25 | 27 | 29 | 25 | 77 | 2.72 | ..... | 12 | 10,591 | ne. | 60 | w. | 12 | 8 | 8 | 15 | 6.5 | 1.5 | .... |
| Baltimore | 123 | 100 | 113 | 29.83 | 29.96 | — .16 | 37.6 | + 4.2 | 72 | 30 | 45 | 5 | 14 | 30 | 31 | 33 | 27 | 70 | 5.66 | + 2.4 | 7 | 5,916 | nw. | 36 | ne. | 3 | 7 | 10 | 14 | 6.6 | T. | .... |
| Washington | 112 | 62 | 85 | 29.83 | 29.95 | — .18 | 38.6 | + 5.7 | 72 | 30 | 47 | 7 | 14 | 30 | 30 | 33 | 28 | 71 | 4.60 | + 1.2 | 6 | 6,884 | nw. | 48 | nw. | 12 | 8 | 12 | 11 | 5.8 | T. | .... |
| Lynchburg | 681 | 83 | 88 | 29.21 | 29.97 | — .18 | 42.0 | + 6.2 | 73 | 28 | 52 | 15 | 14 | 32 | 35 | 35 | 30 | 68 | 3.00 | — 0.7 | 5 | 6,577 | nw. | 38 | nw. | 12 | 11 | 11 | 9 | 5.2 | 1.5 | .... |
| Mount Weather | 1,725 | 10 | 75 | 28.04 | 29.93 | — .20 | 32.6 | + 5.3 | 66 | 30 | 40 | — 1 | 14 | 25 | 30 | 30 | 26 | 78 | 3.69 | + 0.4 | 6 | 15,866 | nw. | 72 | nw. | 12 | 4 | 12 | 15 | 6.9 | 10.3 | .... |
| Norfolk | 91 | 170 | 205 | 29.88 | 29.98 | — .15 | 44.1 | + 3.7 | 73 | 31 | 52 | 18 | 14 | 36 | 26 | 39 | 34 | 71 | 2.32 | — 1.0 | 6 | 12,286 | sw. | 52 | w. | 12 | 12 | 7 | 4 | 4.9 | .... | .... |
| Richmond | 144 | 11 | 52 | 29.82 | 29.98 | — .15 | 41.8 | + 3.8 | 73 | 30 | 51 | 13 | 14 | 32 | 32 | 36 | 32 | 74 | 3.65 | + 0.6 | 7 | 7,195 | sw. | 52 | sw. | 31 | 13 | 8 | 10 | 4.7 | T. | .... |
| Wytheville | 2,293 | 40 | 47 | 27.56 | 30.00 | — .14 | 36.7 | + 3.7 | 72 | 28 | 45 | 13 | 13 | 29 | 38 | 32 | 28 | 77 | 2.61 | — 1.7 | 7 | 6,023 | w. | 33 | w. | 31 | 10 | 7 | 14 | 5.9 | 14.2 | .... |
| *South Atlantic States.* | | | | | | | **47.8** | **+ 2.7** | | | | | | | | | **72** | **2.43** | **— 1.5** | | | | | | | | | **4.6** | | |
| Asheville | 2,255 | 70 | 84 | 27.62 | 30.05 | — .10 | 39.6 | + 4.2 | 75 | 28 | 49 | 17 | 14 | 31 | 42 | 34 | 28 | 71 | 0.89 | — 3.8 | 8 | 8,137 | nw. | 38 | se. | 31 | 14 | 8 | 9 | 4.6 | 3.2 | .... |
| Charlotte | 773 | 68 | 76 | 29.16 | 30.02 | — .13 | 43.8 | + 3.4 | 70 | 30 | 53 | 25 | 14 | 35 | 27 | 37 | 31 | 69 | 2.78 | — 1.5 | 7 | 5,858 | sw. | 36 | sw. | 31 | 13 | 7 | 11 | 5.1 | 0.1 | .... |
| Hatteras | 11 | 12 | 50 | 29.97 | 29.98 | — .16 | 47.6 | + 1.8 | 70 | 30 | 54 | 27 | 14 | 41 | 27 | 44 | 40 | 80 | 1.93 | — 3.0 | 4 | 12,896 | sw. | 47 | nw. | 12 | 20 | 4 | 7 | 4.1 | .... | .... |
| Manteo | 12 | 12 | 46 | ..... | ..... | ..... | 45.4 | ..... | 71 | 30 | 55 | 16 | 15 | 36 | .... | .... | .... | .... | 2.48 | — 2.2 | 3 | ..... | sw. | .... | ..... | ..... | 14 | 12 | 5 | .... | .... | .... |
| Raleigh | 376 | 103 | 110 | 29.58 | 30.00 | — .13 | 45.0 | + 4.6 | 73 | 30 | 54 | 19 | 14 | 36 | 30 | 38 | 31 | 63 | 2.87 | — 0.7 | 5 | 7,244 | sw. | 38 | w. | 24 | 14 | 9 | 8 | 4.6 | T. | .... |
| Wilmington | 78 | 81 | 91 | 29.94 | 30.02 | — .12 | 48.6 | + 3.0 | 75 | 30 | 58 | 24 | 14 | 39 | 28 | 42 | 38 | 73 | 2.02 | — 1.5 | 7 | 6,400 | w. | 35 | s. | 24 | 12 | 12 | 7 | 4.3 | .... | .... |
| Charleston | 48 | 11 | 92 | 29.99 | 30.04 | — .11 | 50.0 | + 0.7 | 72 | 10 | 58 | 33 | 5 | 42 | 26 | 44 | 40 | 76 | 2.10 | — 1.4 | 8 | 8,206 | w. | 35 | sw. | 24 | 14 | 10 | 7 | 4.5 | .... | .... |
| Columbia, S. C. | 351 | 41 | 57 | 29.65 | 30.04 | — .11 | 47.7 | + 2.6 | 74 | 28 | 58 | 27 | 12 | 38 | 32 | 40 | 34 | 67 | 2.92 | — 0.4 | 8 | 5,806 | sw. | 37 | sw. | 9 | 13 | 11 | 7 | 4.6 | T. | .... |
| Augusta | 180 | 89 | 97 | 29.85 | 30.05 | — .11 | 48.5 | + 2.6 | 76 | 29 | 59 | 26 | 14 | 38 | 33 | 42 | 37 | 74 | 3.15 | — 1.0 | 8 | 5,115 | w. | 32 | w. | 31 | 12 | 8 | 11 | 5.4 | .... | .... |
| Savannah | 65 | 150 | 194 | 29.99 | 30.06 | — .09 | 52.4 | + 2.5 | 74 | 29 | 61 | 31 | 7 | 43 | 27 | 45 | 40 | 72 | 2.33 | — 0.8 | 4 | 10,237 | w. | 46 | w. | 3 | 11 | 9 | 11 | 5.4 | .... | .... |
| Jacksonville | 43 | 96 | 129 | 30.02 | 30.08 | — .07 | 55.2 | + 1.3 | 77 | 29 | 64 | 32 | 7 | 46 | 25 | 49 | 44 | 75 | 3.31 | + 0.2 | 10 | 7,757 | w. | 40 | sw. | 16 | 18 | 7 | 6 | 3.5 | .... | .... |
| *Florida Peninsula.* | | | | | | | **63.0** | **— 0.7** | | | | | | | | | **80** | **2.43** | **— 0.3** | | | | | | | | | **5.0** | | |
| Key West | 22 | 10 | 64 | 30.04 | 30.06 | — .04 | 68.1 | — 0.7 | 81 | 10 | 73 | 56 | 13 | 63 | 21 | 62 | 60 | 80 | 1.67 | — 0.3 | 8 | 8,210 | ne. | 32 | sw. | 3 | 16 | 6 | 9 | 4.5 | .... | .... |
| Miami | 25 | 37 | 72 | 30.05 | 30.08 | ..... | 64.4 | — 2.9 | 79 | 10 | 72 | 44 | 5 | 56 | 28 | 59 | 56 | 80 | 1.35 | — 2.1 | 12 | 6,588 | nw. | 29 | e. | 29 | 11 | 9 | 11 | 5.8 | .... | .... |
| Sand Key | 23 | 39 | 72 | 30.02 | 30.05 | — .05 | 68.6 | ..... | 77 | 24 | 72 | 58 | 13 | 65 | 14 | 63 | 60 | 75 | 2.27 | ..... | 10 | 12,306 | ne. | 37 | se. | 29 | 13 | 10 | 8 | 4.9 | .... | .... |
| Tampa | 35 | 79 | 96 | 30.05 | 30.09 | — .03 | 60.0 | + 2.6 | 81 | 29 | 68 | 41 | 4 | 52 | 24 | 54 | 52 | 83 | 4.27 | + 1.5 | 10 | 5,878 | n. | 38 | sw. | 2 | 11 | 8 | 12 | 5.1 | .... | .... |
| Titusville | 44 | 6 | .... | 30.03 | 30.08 | ..... | 59.4 | — 1.7 | 80 | 21 | 69 | 33 | 8 | 50 | 38 | .... | .... | .... | 6.05 | ..... | 10 | ..... | w. | .... | ..... | ..... | 14 | 10 | 7 | 4.8 | .... | .... |
| *East Gulf States.* | | | | | | | **50.5** | **+ 3.1** | | | | | | | | | **72** | **1.91** | **— 3.1** | | | | | | | | | **4.4** | | |
| Atlanta | 1,174 | 190 | 216 | 28.80 | 30.06 | — .09 | 45.0 | + 2.8 | 71 | 30 | 53 | 26 | 13 | 37 | 25 | 39 | 32 | 67 | 1.35 | — 4.0 | 7 | 10,985 | w. | 42 | sw. | 30 | 16 | 5 | 10 | 4.8 | T. | .... |
| Macon | 370 | 78 | 87 | 29.66 | 30.06 | — .10 | 48.4 | + 2.8 | 76 | 30 | 58 | 24 | 14 | 38 | 36 | 42 | 37 | 72 | 2.23 | — 3.0 | 6 | 5,136 | nw. | 36 | w. | 31 | 14 | 8 | 9 | 4.5 | .... | .... |
| Thomasville | 273 | 8 | 57 | 29.78 | 30.08 | — .08 | 52.2 | + 1.2 | 80 | 29 | 64 | 28 | 12 | 40 | 36 | 45 | 41 | 79 | 4.89 | + 0.8 | 5 | 4,719 | nw. | 24 | sw. | 31 | 16 | 9 | 6 | 3.8 | .... | .... |
| Pensacola | 56 | 140 | 182 | 30.04 | 30.10 | — .04 | 54.1 | + 1.8 | 73 | 10 | 61 | 33 | 12 | 47 | 25 | 48 | 44 | 75 | 1.30 | — 2.7 | 5 | 10,164 | nw. | 46 | sw. | 16 | 14 | 10 | 7 | 4.6 | .... | .... |
| Anniston | 741 | 9 | 57 | 29.29 | 30.10 | — .06 | 45.6 | + 3.4 | 73 | 29 | 55 | 22 | 12 | 36 | 34 | .... | .... | .... | 2.61 | — 2.7 | 5 | 5,077 | nw. | 26 | w. | 30 | 12 | 8 | 11 | 4.9 | T. | .... |
| Birmingham | 700 | 11 | 48 | 29.31 | 30.10 | — .06 | 47.4 | + 2.1 | 74 | 29 | 56 | 25 | 12 | 38 | 33 | 41 | 34 | 67 | 1.85 | — 3.5 | 5 | 6,032 | s. | 24 | nw. | 21 | 16 | 5 | 10 | 4.4 | .... | .... |
| Mobile | 57 | 125 | 161 | 30.03 | 30.09 | — .06 | 53.6 | + 3.8 | 74 | 16 | 62 | 32 | 7 | 46 | 24 | 47 | 43 | 73 | 1.98 | — 2.9 | 4 | 7,702 | n. | 34 | nw. | 24 | 15 | 12 | 4 | 3.7 | .... | .... |
| Montgomery | 223 | 100 | 112 | 29.85 | 30.10 | — .06 | 50.0 | + 2.3 | 77 | 29 | 60 | 29 | 7 | 40 | 30 | 44 | 39 | 71 | 2.25 | — 2.9 | 7 | 5,535 | nw. | 27 | sw. | 9 | 16 | 11 | 4 | 3.4 | .... | .... |
| Meridian | 375 | 85 | 93 | 29.68 | 30.08 | — .08 | 49.7 | + 4.7 | 76 | 16 | 60 | 27 | 7 | 40 | 30 | 44 | 40 | 77 | 1.17 | — 4.4 | 3 | 4,535 | sw. | 25 | w. | 30 | 7 | 13 | 11 | 5.8 | .... | .... |
| Vicksburg | 247 | 62 | 74 | 29.80 | 30.09 | — .06 | 52.8 | + 5.8 | 79 | 16 | 62 | 29 | 5 | 43 | 28 | 45 | 38 | 64 | 0.37 | — 5.3 | 5 | 6,195 | se. | 25 | nw. | 20 | 12 | 14 | 5 | 4.3 | .... | .... |
| New Orleans | 51 | 90 | 121 | 30.04 | 30.09 | — .04 | 56.6 | + 3.6 | 78 | 9 | 65 | 36 | 7 | 48 | 26 | 51 | 47 | 77 | 1.02 | — 3.6 | 5 | 6,586 | ne. | 28 | ne. | 21 | 14 | 13 | 4 | 4.0 | .... | .... |
| *West Gulf States.* | | | | | | | **52.5** | **+ 6.3** | | | | | | | | | **68** | **0.72** | **— 2.2** | | | | | | | | | **4.1** | | |
| Shreveport | 249 | 77 | 93 | 29.79 | 30.07 | — .07 | 52.6 | + 6.4 | 78 | 19 | 63 | 29 | 5 | 43 | 33 | 46 | 40 | 69 | 0.73 | — 3.7 | 3 | 6,581 | s. | 30 | s. | 28 | 21 | 3 | 7 | 3.7 | T. | .... |
| Bentonville | 1,303 | 11 | 44 | 28.61 | 30.00 | — .14 | 41.5 | + 7.4 | 74 | 27 | 51 | 14 | 30 | 32 | 40 | .... | .... | .... | 2.42 | — 0.2 | 4 | 5,387 | s. | 28 | s. | 28 | 10 | 9 | 12 | 5.7 | 6.3 | T. |
| Fort Smith | 457 | 79 | 94 | 29.53 | 30.02 | — .12 | 45.0 | + 6.7 | 78 | 27 | 55 | 24 | 6 | 35 | 41 | 38 | 32 | 66 | 0.93 | — 1.6 | 2 | 6,578 | e. | 36 | nw. | 29 | 9 | 8 | 14 | 5.7 | T. | .... |
| Little Rock | 357 | 139 | 147 | 29.66 | 30.04 | — .11 | 47.0 | + 6.4 | 76 | 28 | 56 | 26 | 31 | 38 | 34 | 41 | 35 | 68 | 1.35 | — 3.4 | 5 | 8,166 | nw. | 38 | sw. | 22 | 10 | 14 | 7 | 4.9 | 0.1 | .... |
| Brownsville | 57 | 3 | 40 | ..... | ..... | ..... | 62.6 | ..... | 88 | 25 | 74 | 30 | 31 | 51 | 42 | .... | .... | .... | 0.10 | ..... | 2 | ..... | s. | 30 | ..... | ..... | 29 | .... | .... | .... | .... | .... |
| Corpus Christi | 20 | 69 | 77 | 30.07 | 30.09 | — .01 | 59.4 | + 5.9 | 81 | 25 | 68 | 35 | 31 | 51 | 29 | 53 | 49 | 75 | 0.19 | — 2.1 | 2 | 8,558 | se. | 46 | se. | 27 | 12 | 15 | 4 | 4.6 | .... | .... |
| Dallas | 512 | 109 | 117 | 29.49 | 30.04 | ..... | 52.2 | ..... | 82 | 19 | 64 | 25 | 6 | 41 | 36 | .... | .... | .... | 1.06 | ..... | 3 | 8,080 | se. | 38 | s. | 22 | 11 | 15 | 5 | 4.4 | .... | .... |
| Fort Worth | 670 | 106 | 114 | 29.31 | 30.03 | — .09 | 53.0 | + 8.7 | 82 | 19 | 64 | 26 | 6 | 42 | 36 | 44 | 36 | 61 | 0.43 | — 0.5 | 2 | 8,125 | s. | 36 | s. | 22 | 15 | 10 | 6 | 4.0 | .... | .... |
| Galveston | 54 | 106 | 114 | 30.04 | 30.10 | — .03 | 57.0 | + 4.3 | 73 | 9 | 62 | 38 | 30 | 52 | 24 | 52 | 49 | 79 | 0.34 | — 3.3 | 2 | 8,511 | s. | 38 | nw. | 29 | 19 | 8 | 4 | 3.2 | .... | .... |
| Houston | 138 | 111 | 121 | 29.92 | 30.08 | ..... | 57.6 | + 4.7 | 79 | 17 | 68 | 32 | 6 | 48 | 30 | .... | .... | .... | 0.49 | ..... | 3 | 6,413 | sw. | 29 | se. | 28 | 17 | 9 | 5 | 3.6 | .... | .... |
| Palestine | 510 | 64 | 72 | 29.52 | 30.06 | — .06 | 54.2 | + 7.7 | 82 | 16 | 64 | 29 | 5 | 45 | 34 | 46 | 39 | 65 | 0.62 | — 3.2 | 2 | 6,653 | s. | 35 | s. | 28 | 17 | 8 | 6 | 3.8 | .... | .... |
| San Antonio | 701 | 80 | 91 | 29.35 | 30.09 | — .01 | 56.4 | + 5.3 | 82 | 27 | 68 | 31 | 6 | 44 | 36 | 47 | 38 | 59 | 0.09 | — 1.6 | 2 | 4,672 | n. | 30 | nw. | 29 | 24 | 4 | 3 | 2.2 | .... | .... |
| Taylor | 583 | 55 | 63 | 29.47 | 30.09 | — .02 | 53.7 | + 6.2 | 82 | 16 | 65 | 36 | 6 | 42 | 37 | .... | .... | .... | 0.09 | — 2.7 | 3 | 7,561 | sw. | 44 | s. | 28 | 17 | 10 | 4 | 3.3 | .... | .... |

TABLE I.—*Climatological data for United States Weather Bureau stations, January, 1914*—Continued.

| Districts and stations. | Elevation of instruments. | | | Pressure in inches. | | | Temperature of the air, in degrees Fahrenheit. | | | | | | | | | | Mean wet thermometer. | Mean temperature of the dew point. | Mean relative humidity, per cent. | Precipitation, inches. | | | Wind. | | | | | Clear days. | Partly cloudy days. | Cloudy days. | Average cloudiness, tenths. | Total snowfall. | Snow on ground at end of month. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Barometer above sea level, feet. | Thermometer above ground. | Anemometer above ground. | Station, reduced to mean of 24 hours. | Sea level, reduced to mean of 24 hour's. | Departure from normal | Mean max.+mean min.÷2. | Departure from normal. | Maximum. | Date. | Mean maximum. | Minimum. | Date. | Mean minimum. | Greatest daily range. | | | | | Total. | Departure from normal. | Days with 0.01 or more. | Total movement, miles. | Prevailing direction. | Maximum velocity. Miles per hour. | Maximum velocity. Direction. | Maximum velocity. Date. | | | | | | |
| *Ohio Valley and Tennessee.* | | | | | | | **38.4** | **+ 5.2** | | | | | | | | **77** | **2.24** | **− 1.6** | | | | | | | | | | **7.2** | | |
| Chattanooga | 762 | 189 | 213 | 29.25 | 30.08 | − .08 | 43.8 | + 3.2 | 70 | 28 | 52 | 24 | 13 | 36 | 30 | 39 | 33 | 68 | 4.52 | − 1.0 | 7 | 7,015 | nw. | 43 | sw. | 30 | 11 | 8 | 12 | 5.8 | 2.6 | .... |
| Knoxville | 996 | 93 | 100 | 28.96 | 30.04 | − .11 | 41.6 | + 4.1 | 73 | 29 | 50 | 21 | 13 | 33 | 35 | 37 | 33 | 76 | 1.64 | − 3.3 | 7 | 4,218 | sw. | 32 | sw. | 31 | 5 | 11 | 15 | 6.8 | 5.3 | .... |
| Memphis | 399 | 76 | 97 | 29.64 | 30.08 | − .08 | 46.1 | + 5.8 | 73 | 28 | 54 | 27 | 13 | 38 | 37 | 42 | 39 | 77 | 1.60 | − 3.6 | 6 | 7,923 | sw. | 34 | nw. | 20 | 8 | 10 | 13 | 5.9 | T. | .... |
| Nashville | 546 | 168 | 191 | 29.46 | 30.06 | − .10 | 42.6 | + 4.6 | 68 | 28 | 50 | 20 | 13 | 35 | 32 | 38 | 32 | 70 | 1.56 | − 3.3 | 5 | 8,784 | s. | 37 | sw. | 31 | 7 | 8 | 16 | 6.7 | T. | .... |
| Lexington | 989 | 75 | 102 | 28.91 | 30.01 | − .12 | 37.2 | + 4.2 | 66 | 28 | 44 | 13 | 13 | 30 | 26 | .... | .... | .... | 2.50 | − 1.3 | 6 | 10,086 | s. | 44 | sw. | 31 | 7 | 8 | 16 | 6.9 | 1.4 | T. |
| Louisville | 525 | 219 | 255 | 29.43 | 30.03 | − .11 | 39.0 | + 4.7 | 69 | 28 | 46 | 16 | 13 | 32 | 30 | 35 | 31 | 75 | 1.84 | − 2.1 | 6 | 11,596 | s. | 48 | sw. | 31 | 4 | 11 | 16 | 7.0 | 0.7 | T. |
| Evansville | 431 | 72 | 82 | 29.53 | 30.01 | − .13 | 39.6 | + 7.3 | 68 | 29 | 46 | 17 | 13 | 33 | 37 | 36 | 32 | 77 | 1.92 | − 1.8 | 6 | 7,272 | s. | 36 | s. | 23 | 6 | 9 | 16 | 7.2 | 2.5 | T. |
| Indianapolis | 822 | 154 | 164 | 29.07 | 29.98 | − .14 | 34.6 | + 6.4 | 65 | 28 | 41 | 10 | 12 | 28 | 35 | 32 | 28 | 78 | 2.76 | 0.0 | 11 | 9,261 | sw. | 37 | sw. | 29 | 4 | 4 | 23 | 8.1 | 9.6 | 3.2 |
| Terre Haute | 575 | 96 | 129 | 29.34 | 29.97 | ..... | 36.0 | ..... | 66 | 28 | 43 | 11 | 12 | 29 | 33 | 33 | 31 | 84 | 2.30 | ..... | 10 | 9,033 | s. | 33 | nw. | 12 | 2 | 9 | 20 | 8.1 | 7.0 | 4.5 |
| Cincinnati | 628 | 152 | 160 | 29.30 | 29.99 | − .13 | 37.8 | + 5.5 | 68 | 29 | 45 | 13 | 13 | 31 | 29 | 35 | 32 | 83 | 2.37 | − 1.0 | 7 | 6,254 | sw. | 31 | sw. | 31 | 2 | 10 | 19 | 7.9 | 1.5 | T. |
| Columbus | 824 | 173 | 222 | 29.06 | 29.96 | − .15 | 34.0 | + 5.4 | 66 | 28 | 40 | 7 | 13 | 28 | 30 | 32 | 28 | 81 | 2.21 | − 0.7 | 12 | 10,532 | sw. | 52 | nw. | 12 | 10 | 5 | 16 | 6.5 | 7.6 | 0.1 |
| Dayton | 899 | 181 | 216 | 28.98 | 29.95 | ..... | 34.4 | + 5.5 | 66 | 28 | 41 | 8 | 13 | 28 | 31 | 32 | 29 | 82 | 2.19 | − 0.8 | 8 | 10,482 | s. | 48 | w. | 12 | 6 | 6 | 19 | 7.4 | 5.7 | 0.2 |
| Pittsburgh | 842 | 353 | 410 | 29.02 | 29.95 | − .16 | 34.4 | + 3.7 | 72 | 29 | 41 | 3 | 14 | 28 | 35 | 31 | 27 | 76 | 2.41 | − 0.5 | 17 | 10,558 | sw. | 51 | sw. | 31 | 2 | 8 | 21 | 8.3 | 17.3 | T. |
| Elkins | 1,940 | 41 | 50 | 27.87 | 29.98 | − .14 | 35.2 | + 6.2 | 78 | 29 | 43 | 1 | 14 | 27 | 42 | 32 | 28 | 81 | 2.31 | − 1.0 | 17 | 3,949 | w. | 26 | w. | 21 | 4 | 4 | 23 | 8.0 | 13.4 | T. |
| Parkersburg | 638 | 77 | 84 | 29.32 | 29.99 | − .13 | 37.6 | + 6.3 | 73 | 29 | 44 | 12 | 14 | 31 | 33 | 33 | 28 | 73 | 1.55 | − 1.6 | 12 | 5,755 | s. | 38 | nw. | 12 | 6 | 4 | 21 | 7.6 | 2.9 | .... |
| *Lower Lake Region.* | | | | | | | **27.7** | **+ 3.4** | | | | | | | | **82** | **2.65** | **0.0** | | | | | | | | | | **8.1** | | |
| Buffalo | 767 | 247 | 280 | 29.05 | 29.90 | − .17 | 27.9 | + 3.2 | 59 | 29 | 35 | −10 | 13 | 21 | 35 | 26 | 23 | 82 | 3.96 | + 0.7 | 19 | 15,130 | sw. | 92 | sw. | 31 | 0 | 10 | 21 | 8.5 | 23.2 | 3.2 |
| Canton | 448 | 10 | 61 | 29.45 | 29.95 | ..... | 13.0 | − 3.3 | 53 | 30 | 24 | −31 | 13 | 2 | 42 | .... | .... | .... | 1.70 | − 1.5 | 17 | 9,482 | e. | 53 | sw. | 31 | 13 | 4 | 14 | 5.4 | 14.5 | 1.5 |
| Oswego | 335 | 76 | 91 | 29.55 | 29.93 | − .14 | 23.7 | − 0.2 | 50 | 29 | 31 | −21 | 13 | 16 | 31 | 22 | 20 | 85 | 1.79 | − 1.4 | 18 | 9,300 | s. | 43 | n. | 12 | 2 | 4 | 25 | 8.7 | 10.1 | .... |
| Rochester | 523 | 86 | 102 | 29.34 | 29.94 | − .13 | 27.0 | + 3.0 | 59 | 29 | 34 | −11 | 13 | 20 | 30 | 24 | 21 | 78 | 2.97 | − 0.2 | 19 | 7,108 | w. | 40 | w. | 31 | 1 | 8 | 22 | 8.5 | 15.1 | 1.0 |
| Syracuse | 597 | 97 | 113 | 29.27 | 29.94 | − .13 | 24.5 | + 1.5 | 54 | 30 | 33 | −22 | 13 | 16 | 34 | 22 | 19 | 82 | 2.55 | + 0.4 | 16 | 9,373 | s. | 48 | nw. | 12 | 4 | 6 | 21 | 7.8 | 16.1 | .... |
| Erie | 714 | 92 | 102 | 29.12 | 29.91 | − .17 | 31.0 | + 4.5 | 65 | 29 | 37 | − 3 | 14 | 25 | 33 | 28 | 25 | 78 | 3.14 | + 0.1 | 15 | 10,871 | s. | 49 | nw. | 12 | 1 | 3 | 27 | 8.7 | 22.3 | 0.6 |
| Cleveland | 762 | 190 | 201 | 29.08 | 29.93 | − .16 | 32.0 | + 6.2 | 65 | 29 | 38 | 2 | 14 | 26 | 34 | 30 | 26 | 78 | 1.61 | − 0.8 | 19 | 12,885 | se. | 60 | w. | 12 | 3 | 3 | 25 | 8.3 | 10.6 | T. |
| Sandusky | 629 | 62 | 70 | 29.24 | 29.94 | − .15 | 32.2 | + 5.9 | 65 | 29 | 38 | 8 | 14 | 26 | 31 | 30 | 27 | 83 | 2.71 | + 0.6 | 14 | 7,520 | sw. | 44 | nw. | 12 | 1 | 7 | 23 | 8.6 | 16.1 | 0.8 |
| Toledo | 628 | 208 | 246 | 29.24 | 29.93 | − .16 | 32.0 | + 6.4 | 62 | 29 | 38 | 8 | 14 | 26 | 29 | 29 | 26 | 81 | 2.85 | + 0.9 | 17 | 12,597 | sw. | 48 | sw. | 11 | 3 | 4 | 24 | 8.2 | 14.0 | 7.0 |
| Fort Wayne | 856 | 113 | 124 | 28.99 | 29.94 | ..... | 32.3 | + 5.4 | 64 | 28 | 38 | 8 | 12 | 26 | 34 | 30 | 27 | 82 | 2.25 | ..... | 13 | 8,735 | sw. | 36 | sw. | 29 | 5 | 3 | 23 | 8.1 | 15.0 | 7.1 |
| Detroit | 730 | 218 | 258 | 29.10 | 29.92 | − .16 | 29.4 | + 5.1 | 58 | 29 | 36 | 4 | 13 | 23 | 29 | 27 | 25 | 86 | 3.26 | + 1.3 | 19 | 10,160 | w. | 42 | w. | 11 | 1 | 8 | 22 | 8.5 | 21.8 | 7.2 |
| *Upper Lake Region.* | | | | | | | **24.3** | **+ 6.1** | | | | | | | | **84** | **2.39** | **+ 0.4** | | | | | | | | | | **8.8** | | |
| Alpena | 609 | 13 | 92 | 29.23 | 29.92 | − .12 | 22.6 | + 3.9 | 47 | 29 | 29 | − 8 | 13 | 16 | 28 | 22 | 20 | 88 | 3.41 | + 1.2 | 20 | 9,529 | nw. | 38 | s. | 14 | 0 | 7 | 24 | 8.7 | 37.2 | 15.5 |
| Escanaba | 612 | 54 | 60 | 29.22 | 29.91 | − .14 | 22.3 | + 7.8 | 42 | 29 | 29 | − 7 | 25 | 16 | 39 | 22 | 19 | 85 | 1.57 | 0.0 | 14 | 7,519 | n. | 36 | nw. | 11 | 3 | 1 | 27 | 8.7 | 9.3 | 1.2 |
| Grand Haven | 632 | 54 | 92 | 29.21 | 29.91 | − .16 | 28.9 | + 4.4 | 57 | 29 | 35 | 4 | 13 | 23 | 36 | 28 | 25 | 84 | 3.29 | + 0.5 | 15 | 10,066 | n. | 50 | nw. | 11 | 0 | 2 | 29 | 9.4 | 22.3 | 9.0 |
| Grand Rapids | 707 | 70 | 87 | 29.12 | 29.92 | − .14 | 29.0 | − 5.2 | 59 | 29 | 35 | 4 | 13 | 23 | 35 | 28 | 26 | 85 | 3.24 | + 0.5 | 14 | 5,367 | nw. | 28 | w. | 29 | 0 | 4 | 27 | 9.4 | 27.0 | 12.0 |
| Houghton | 684 | 62 | 72 | 29.14 | 29.89 | − .16 | 20.4 | − 5.9 | 40 | 29 | 27 | − 6 | 12 | 14 | 39 | .... | .... | .... | 2.82 | + 0.8 | 19 | 6,690 | e. | 40 | w. | 29 | 2 | 4 | 25 | 8.7 | 25.6 | 11.0 |
| Lansing | 878 | 11 | 62 | 28.94 | 29.90 | ..... | 27.0 | + 5.0 | 54 | 29 | 34 | − 1 | 13 | 20 | 34 | 26 | 24 | 88 | 2.98 | + 0.9 | 17 | 5,070 | sw. | 24 | se. | 26 | 0 | 3 | 28 | 9.3 | 25.2 | 10.0 |
| Ludington | 637 | 60 | 66 | 29.19 | 29.90 | ..... | 27.6 | ..... | 55 | 28 | 34 | 2 | 13 | 22 | 39 | 27 | 24 | 84 | 1.60 | ..... | 19 | 9,466 | se. | 39 | nw. | 11 | 1 | 1 | 29 | 9.5 | 9.2 | 0.9 |
| Marquette | 734 | 77 | 111 | 29.10 | 29.93 | − .11 | 21.8 | + 5.9 | 44 | 29 | 28 | − 4 | 12 | 16 | 44 | 21 | 18 | 83 | 2.63 | + 0.6 | 19 | 8,541 | nw. | 38 | sw. | 29 | 2 | 6 | 23 | 8.4 | 24.9 | 12.9 |
| Port Huron | 638 | 70 | 120 | 29.19 | 29.91 | − .15 | 26.8 | + 5.0 | 54 | 29 | 33 | − 5 | 13 | 20 | 37 | 26 | 23 | 84 | 2.14 | + 0.2 | 14 | 9,782 | sw. | 42 | nw. | 12 | 1 | 5 | 25 | 8.8 | 14.6 | 3.0 |
| Saginaw | 641 | 48 | 82 | 29.20 | 29.91 | ..... | 25.8 | ..... | 55 | 29 | 33 | − 1 | 13 | 19 | 35 | 26 | 24 | 91 | 3.11 | + 0.8 | 16 | 8,266 | s. | 36 | nw. | 11 | 1 | 2 | 28 | 9.4 | 22.6 | 12.5 |
| Sault Ste. Marie | 614 | 11 | 61 | 29.21 | 29.94 | − .09 | 17.3 | + 4.0 | 48 | 29 | 26 | −26 | 13 | 9 | 41 | 16 | 14 | 86 | 1.88 | − 0.3 | 18 | 6,958 | se. | 39 | w. | 29 | 5 | 2 | 24 | 8.1 | 17.7 | 10.3 |
| Chicago | 823 | 140 | 310 | 29.04 | 29.94 | − .16 | 32.4 | + 8.7 | 60 | 28 | 39 | 4 | 12 | 26 | 36 | 30 | 25 | 73 | 3.01 | + 1.0 | 13 | 10,216 | sw. | 37 | w. | 12 | 4 | 4 | 23 | 8.1 | 14.8 | 9.3 |
| Green Bay | 617 | 109 | 144 | 29.22 | 29.90 | − .18 | 23.8 | + 9.2 | 50 | 29 | 30 | − 6 | 12 | 18 | 41 | 23 | 20 | 81 | 0.91 | − 0.8 | 11 | 8,917 | n. | 43 | w. | 29 | 3 | 1 | 27 | 8.7 | 5.1 | T. |
| Milwaukee | 681 | 119 | 133 | 29.16 | 29.91 | − .17 | 28.8 | + 9.0 | 56 | 29 | 35 | − 3 | 12 | 23 | 39 | 27 | 23 | 78 | 0.75 | − 1.3 | 8 | 8,051 | sw. | 32 | s. | 26 | 3 | 3 | 25 | 8.5 | 5.2 | .... |
| Duluth | 1,133 | 11 | 47 | 28.66 | 29.94 | − .15 | 15.4 | + 5.0 | 39 | 14 | 23 | −18 | 12 | 8 | 40 | 14 | 12 | 89 | 1.75 | + 0.8 | 12 | 9,595 | nw. | 49 | nw. | 9 | 1 | 8 | 22 | 8.3 | 13.5 | 2.9 |
| *North Dakota.* | | | | | | | **14.8** | **+10.7** | | | | | | | | **82** | **0.48** | **− 0.1** | | | | | | | | | | **6.2** | | |
| Moorhead | 940 | 8 | 57 | 28.92 | 29.99 | − .15 | 14.1 | +11.4 | 44 | 7 | 24 | −15 | 12 | 4 | 34 | 13 | 10 | 86 | 0.51 | − 0.2 | 9 | 7,451 | nw. | 35 | nw. | 28 | 7 | 7 | 17 | 6.5 | 5.0 | 2.0 |
| Bismarck | 1,674 | 8 | 57 | 28.11 | 29.98 | − .15 | 17.9 | +11.2 | 56 | 7 | 29 | −14 | 29 | 7 | 51 | 15 | 11 | 77 | 0.25 | − 0.3 | 5 | 7,872 | nw. | 46 | nw. | 28 | 6 | 16 | 9 | 5.9 | 5.0 | 1.4 |
| Devils Lake | 1,482 | 11 | 44 | 28.27 | 29.93 | − .19 | 9.6 | + 9.3 | 44 | 7 | 20 | −22 | 24 | −1 | 49 | 8 | 6 | 89 | 0.61 | 0.0 | 10 | 8,760 | nw. | 44 | nw. | 28 | 5 | 11 | 15 | 6.5 | 9.3 | 4.8 |
| Williston | 1,872 | 40 | 47 | 27.84 | 29.90 | − .21 | 17.4 | +10.9 | 50 | 5 | 29 | −24 | 24 | 6 | 43 | 15 | 10 | 76 | 0.55 | 0.0 | 7 | 5,954 | nw. | 47 | w. | 15 | 8 | 10 | 13 | 6.0 | 4.6 | 1.5 |
| *Upper Mississippi Valley.* | | | | | | | **31.1** | **+ 9.6** | | | | | | | | **80** | **1.28** | **− 0.5** | | | | | | | | | | **7.4** | | |
| Minneapolis | 918 | 102 | 208 | ..... | ..... | ..... | 21.4 | ..... | 43 | 14 | 29 | −10 | 12 | 14 | 34 | .... | .... | .... | 0.83 | + 0.1 | 8 | 9,064 | nw. | 44 | nw. | 11 | 3 | 8 | 20 | 7.9 | 7.7 | 0.2 |
| St. Paul | 837 | 201 | 236 | 29.00 | 29.94 | − .17 | 21.2 | + 9.6 | 43 | 14 | 29 | −10 | 12 | 13 | 33 | 20 | 16 | 76 | 1.05 | + 0.2 | 8 | 10,168 | nw. | 51 | nw. | 11 | 3 | 9 | 19 | 7.7 | 6.8 | T. |
| La Crosse | 714 | 11 | 48 | 29.15 | 29.95 | − .16 | 25.5 | +10.3 | 49 | 29 | 33 | − 7 | 12 | 18 | 38 | .... | .... | .... | 1.63 | + 0.6 | 9 | 4,683 | s. | 28 | nw. | 11 | 2 | 5 | 24 | 8.4 | 8.3 | T. |
| Madison | 974 | 70 | 78 | 28.85 | 29.95 | − .15 | 25.9 | + 9.4 | 53 | 29 | 32 | − 3 | 12 | 19 | 39 | 24 | 21 | 83 | 0.70 | − 0.9 | 6 | 8,200 | nw. | 39 | nw. | 11 | 2 | 6 | 23 | 8.6 | 5.0 | T. |
| Charles City | 1,015 | 10 | 49 | 28.84 | 29.95 | − .19 | 24.4 | +13.0 | 52 | 14 | 33 | − 6 | 12 | 16 | 37 | 22 | 20 | 87 | 1.14 | + 0.2 | 9 | 6,424 | nw. | 27 | se. | 1 | 3 | 11 | 17 | 7.5 | 6.9 | T. |
| Davenport | 606 | 71 | 79 | 29.28 | 29.96 | − .16 | 30.6 | + 9.8 | 57 | 28 | 38 | 2 | 12 | 24 | 38 | 28 | 25 | 83 | 0.87 | − 0.7 | 7 | 6,403 | nw. | 30 | nw. | 29 | 5 | 5 | 21 | 7.5 | 4.3 | T. |
| Des Moines | 861 | 84 | 97 | 29.02 | 29.95 | − .19 | 29.8 | − 9.2 | 57 | 19 | 38 | 1 | 12 | 21 | 34 | 27 | 23 | 78 | 0.85 | − 0.4 | 5 | 6,500 | nw. | 28 | nw. | 16 | 8 | 5 | 18 | 6.6 | 6.8 | .... |
| Dubuque | 698 | 81 | 96 | 29.19 | 29.97 | − .15 | 28.2 | + 9.9 | 54 | 29 | 36 | 0 | 12 | 21 | 38 | 26 | 23 | 83 | 0.78 | − 0.7 | 10 | 5,626 | nw. | 34 | nw. | 11 | 3 | 5 | 23 | 8.2 | 6.7 | T. |
| Keokuk | 614 | 64 | 78 | 29.29 | 29.99 | − .15 | 34.0 | +10.3 | 64 | 28 | 42 | 4 | 12 | 26 | 38 | 31 | 27 | 80 | 1.31 | − 0.4 | 7 | 6,763 | nw. | 30 | w. | 20 | 6 | 11 | 14 | 6.6 | 1.8 | .... |
| Cairo | 356 | 87 | 93 | 29.62 | 30.02 | − .14 | 41.6 | + 6.8 | 69 | 28 | 49 | 18 | 13 | 34 | 37 | 37 | 33 | 74 | 1.64 | − 2.2 | 8 | 8,018 | s. | 35 | n. | 29 | 7 | 8 | 16 | 6.8 | 0.2 | T. |
| Peoria | 609 | 11 | 45 | ..... | ..... | ..... | 32.2 | + 9.1 | 62 | 28 | 39 | 6 | 12 | 25 | 39 | .... | .... | .... | 1.93 | − 0.3 | 9 | 6,679 | nw. | 30 | nw. | 11 | 6 | 4 | 21 | .... | 8.6 | .... |
| Springfield Ill. | 644 | 10 | 91 | 29.27 | 29.98 | − .15 | 35.4 | + 9.1 | 65 | 28 | 42 | 9 | 12 | 28 | 36 | 32 | 28 | 79 | 2.13 | − 0.1 | 8 | 8,195 | nw. | 28 | s. | 26 | 4 | 6 | 21 | 7.7 | 14.5 | 10.0 |
| Hannibal | 534 | 74 | 109 | 29.39 | 29.98 | − .15 | 35.8 | + 9.1 | 64 | 29 | 44 | 7 | 12 | 28 | 42 | .... | .... | .... | 0.88 | − 1.3 | 8 | 7,819 | nw. | 38 | sw. | 14 | 7 | 11 | 13 | 6.4 | 2.6 | T. |
| St. Louis | 567 | 265 | 303 | 29.36 | 29.98 | − .16 | 39.7 | + 8.7 | 68 | 28 | 48 | 15 | 12 | 32 | 40 | 35 | 30 | 75 | 2.21 | − 0.1 | 9 | 12,023 | nw. | 45 | s. | 23 | 8 | 11 | 12 | 6.2 | 3.0 | 2.0 |
| *Missouri Valley.* | | | | | | | **31.8** | **+10.7** | | | | | | | | **76** | **0.50** | **− 0.6** | | | | | | | | | | **5.6** | | |
| Columbia, Mo | 784 | 11 | 84 | 29.14 | 30.00 | − .13 | 37.8 | +10.6 | 66 | 19 | 46 | 11 | 12 | 29 | 40 | .... | .... | .... | 0.55 | − 1.7 | 7 | 7,321 | nw. | 34 | sw. | 29 | 4 | 8 | 19 | 7.5 | 1.6 | T. |
| Kansas City | 963 | 161 | 181 | 28.94 | 30.00 | − .15 | 36.4 | +10.2 | 65 | 19 | 44 | 10 | 12 | 28 | 30 | 32 | 28 | 74 | 0.28 | − 0.8 | 5 | 9,684 | nw. | 45 | nw. | 20 | 11 | 9 | 11 | 5.4 | 0.1 | .... |
| St. Joseph | 967 | 11 | 49 | 28.82 | 29.99 | ..... | 33.9 | ..... | 63 | 19 | 42 | 8 | 12 | 26 | 32 | 30 | 26 | 77 | 0.27 | ..... | 3 | 7,124 | nw. | 42 | nw. | 28 | 10 | 10 | 11 | 5.5 | 0.8 | .... |
| Springfield, Mo | 1,324 | 98 | 104 | 28.58 | 30.01 | − .13 | 39.5 | + 8.2 | 68 | 8 | 49 | 13 | 30 | 30 | 44 | 34 | 29 | 75 | 1.80 | − 0.9 | 5 | 8,577 | s. | 34 | s. | 23 | 9 | 7 | 15 | 6.1 | 6.2 | T. |
| Iola | 984 | 11 | 50 | 28.94 | 30.02 | − .12 | 37.2 | + 9.6 | 64 | 28 | 46 | 17 | 30 | 28 | 31 | .... | .... | .... | 0.39 | − 0.6 | 3 | 5,890 | s. | 27 | sw. | 20 | 12 | 12 | 7 | 4.8 | 0.4 | .... |
| Topeka | 983 | 85 | 101 | ..... | ..... | ..... | 35.8 | +10.2 | 65 | 19 | 44 | 12 | 12 | 27 | 32 | .... | .... | .... | 0.07 | − 0.9 | 4 | 7,793 | s. | 35 | n. | 29 | 8 | 15 | 8 | 5.3 | 0.3 | .... |
| Lincoln | 1,189 | 11 | 84 | 28.68 | 29.98 | − .17 | 32.1 | +10.9 | 57 | 26 | 40 | 5 | 12 | 24 | 37 | 28 | 25 | 79 | 0.28 | − 0.3 | 3 | 8,509 | s. | 44 | n. | 28 | 11 | 10 | 10 | 5.2 | 0.6 | .... |
| Omaha | 1,105 | 115 | 121 | 28.76 | 29.98 | − .17 | 30.6 | +10.1 | 57 | 28 | 39 | 3 | 12 | 23 | 36 | 27 | 23 | 76 | 0.56 | − 0.1 | 7 | 7,349 | s. | 36 | nw. | 9 | 11 | 10 | 10 | 5.2 | 2.2 | .... |
| Valentine | 2,598 | 47 | 54 | 27.17 | 29.96 | − .16 | 31.3 | +13.1 | 63 | 18 | 45 | − 2 | 29 | 18 | 41 | 25 | 19 | 68 | 0.07 | − 0.4 | 4 | 7,907 | w. | 50 | nw. | 1 | 11 | 14 | 6 | 4.6 | 0.8 | .... |
| Sioux City | 1,135 | 94 | 164 | 28.72 | 29.98 | − .17 | 26.6 | +11.0 | 53 | 15 | 36 | − 2 | 12 | 17 | 39 | 24 | 21 | 81 | 0.74 | + 0.2 | 8 | 10,158 | nw. | 52 | nw. | 28 | 11 | 11 | 9 | 5.2 | 7.4 | .... |
| Huron | 1,306 | 56 | 67 | 29.54 | 29.99 | − .17 | 21.3 | +11.8 | 54 | 15 | 32 | − 8 | 12 | 11 | 40 | 19 | 16 | 81 | 0.30 | − 0.2 | 4 | 7,817 | nw. | 44 | nw. | 28 | 8 | 7 | 16 | 6.4 | 2.1 | .... |
| Pierre | 1,572 | 70 | 75 | 28.27 | 29.99 | − .14 | 25.5 | +11.6 | 54 | 7 | 35 | − 1 | 29 | 16 | 39 | 22 | 16 | 70 | 0.43 | 0.0 | 2 | 7,248 | e. | 48 | nw. | 1 | 6 | 15 | 10 | 5.5 | 3.1 | T. |
| Yankton | 1,233 | 49 | 57 | 28.59 | 29.96 | − .20 | 27.0 | +11.5 | 64 | 15 | 37 | − 2 | 12 | 17 | 45 | .... | .... | .... | 0.55 | 0.0 | 7 | 6,205 | nw. | 31 | nw. | 1 | 7 | 11 | 13 | 6.3 | 5.2 | .... |

TABLE I.—*Climatological data for United States Weather Bureau stations, January, 1914*—Continued.

| Districts and stations. | Elevation of instruments. | | | Pressure in inches. | | | Temperature of the air, in degrees Fahrenheit. | | | | | | | | | | Mean wet thermometer. | Mean temperature of the dew point. | Mean relative humidity, per cent. | Precipitation, inches. | | | Wind. | | | | Clear days. | Partly cloudy days. | Cloudy days. | Average cloudiness, tenths. | Total snowfall. | Snow on ground at end of month. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Barometer above sea level, feet. | Thermometer above ground. | Anemometer above ground. | Station, reduced to mean of 24 hours. | Sea level, reduced to mean of 24 hours. | Departure from normal. | Mean max.+mean min.÷2. | Departure from normal. | Maximum. | Date. | Mean maximum. | Minimum. | Date. | Mean minimum. | Greatest daily range. | | | | | Total. | Departure from normal. | Days with 0.01 or more. | Total movement, miles. | Prevailing direction. | Maximum velocity. Miles per hour. | Maximum velocity. Direction. | Maximum velocity. Date. | | | | | |
| *Northern Slope.* | | | | | | | **28.3** | **+ 9.3** | | | | | | | | | | | **68** | **0.49** | **− 0.4** | | | | | | | | **6.1** | | |
| Havre | 2,505 | 11 | 44 | 27.16 | 29.89 | − .21 | 18.8 | + 5.3 | 59 | 7 | 29 | −20 | 29 | 8 | 58 | | 17 | 14 | 83 | 0.64 | 0.0 | 8 | 5,956 | sw. | 36 | sw. | 29 | 4 | 15 | 12 | 6.7 | 6.4 | 3.0 |
| Helena | 4,110 | 87 | 114 | 25.60 | 29.88 | − .27 | 31.2 | +11.2 | 61 | 6 | 40 | 0 | 24 | 23 | 37 | | 26 | 18 | 60 | 0.40 | − 0.5 | 8 | 6,553 | sw. | 62 | sw. | 1 | 3 | 11 | 17 | 7.0 | 5.5 | T. |
| Kalispell | 2,962 | 11 | 34 | 26.74 | 29.86 | − .26 | 29.2 | + 9.6 | 50 | 7 | 37 | 8 | 28 | 22 | 23 | | 27 | 23 | 78 | 1.31 | − 0.3 | 12 | 2,913 | sw. | 23 | sw. | 30 | 2 | 6 | 23 | 8.3 | 10.9 | 3.9 |
| Miles City | 2,371 | 26 | 48 | 27.32 | 29.95 | − .17 | 28.1 | +13.6 | 55 | 22 | 39 | − 8 | 29 | 17 | 48 | | 23 | 19 | 76 | 0.53 | − 0.1 | 11 | 3,816 | se. | 38 | w. | 1 | 12 | 14 | 5 | 4.3 | 3.6 | T. |
| Rapid City | 3,234 | 46 | 50 | 26.46 | 29.95 | − .15 | 33.6 | +12.1 | 65 | 7 | 47 | 1 | 29 | 20 | 50 | | 26 | 17 | 56 | 0.01 | − 0.4 | 1 | 5,751 | w. | 48 | sw. | 18 | 8 | 9 | 14 | 6.3 | T. | .... |
| Cheyenne | 6,088 | 58 | 64 | 23.88 | 29.98 | − .07 | 31.4 | + 5.8 | 53 | 7 | 40 | 5 | 29 | 22 | 28 | | 25 | 18 | 60 | 0.10 | − 0.3 | 3 | 15,051 | w. | 70 | w. | 25 | 10 | 11 | 10 | 5.4 | 0.8 | 0.3 |
| Lander | 5,372 | 60 | 68 | 24.52 | 30.03 | − .09 | 23.6 | + 6.2 | 48 | 15 | 36 | − 8 | 12 | 11 | 45 | | 19 | 11 | 59 | 0.08 | − 0.4 | 2 | 4,657 | w. | 54 | sw. | 25 | 9 | 17 | 5 | 4.9 | 0.6 | T. |
| Sheridan | 3,790 | 10 | 47 | 25.94 | 29.94 | ..... | 29.2 | ..... | 57 | 18 | 44 | 0 | 29 | 14 | 53 | | 22 | 14 | 61 | 0.35 | ..... | 7 | 4,550 | nw. | 52 | nw. | 1 | 5 | 13 | 13 | 5.8 | 4.0 | .... |
| Yellowstone Park | 6,200 | 11 | 48 | 23.73 | 29.98 | − .16 | 24.6 | + 7.0 | 44 | 6 | 32 | 1 | 28 | 18 | 30 | | 22 | 17 | 70 | 1.15 | − 1.1 | 14 | 7,988 | s. | 37 | sw. | 22 | 3 | 6 | 22 | 7.8 | 11.0 | 7.0 |
| North Platte | 2,821 | 11 | 51 | 27.01 | 30.02 | − .10 | 34.0 | +12.6 | 65 | 26 | 46 | 2 | 29 | 22 | 41 | | 27 | 23 | 76 | 0.18 | − 0.3 | 4 | 5,164 | w. | 34 | nw. | 1 | 12 | 14 | 5 | 4.3 | 1.8 | .... |
| *Middle Slope.* | | | | | | | **39.2** | **+10.1** | | | | | | | | | | | **64** | **0.10** | **− 0.6** | | | | | | | | **4.0** | | |
| Denver | 5,291 | 129 | 172 | 24.63 | 29.98 | − .07 | 36.8 | + 7.7 | 64 | 18 | 48 | 10 | 29 | 26 | 38 | | 29 | 18 | 53 | 0.03 | − 0.4 | 3 | 6,952 | sw. | 46 | nw. | 25 | 15 | 15 | 1 | 3.6 | 0.4 | .... |
| Pueblo | 4,685 | 80 | 86 | 25.22 | 29.98 | − .07 | 38.6 | + 9.5 | 64 | 15 | 50 | 6 | 29 | 27 | 43 | | 30 | 21 | 54 | 0.18 | − 0.2 | 2 | 5,763 | w. | 36 | nw. | 1 | 16 | 15 | 0 | 3.0 | 1.6 | .... |
| Concordia | 1,398 | 42 | 50 | 28.49 | 30.01 | − .13 | 36.2 | +11.8 | 73 | 26 | 45 | 13 | 12 | 27 | 41 | | 31 | 27 | 77 | 0.17 | − 0.6 | 2 | 5,048 | sw. | 34 | nw. | 2 | 11 | 10 | 10 | 5.5 | 1.1 | .... |
| Dodge City | 2,509 | 11 | 51 | 27.35 | 30.01 | − .10 | 39.4 | +12.1 | 71 | 7 | 52 | 15 | 11 | 27 | 42 | | 31 | 25 | 65 | 0.18 | − 0.3 | 1 | 7,364 | nw. | 38 | nw. | 28 | 16 | 12 | 3 | 3.5 | 2.0 | .... |
| Wichita | 1,358 | 139 | 158 | 28.52 | 29.98 | − .15 | 38.5 | + 8.8 | 66 | 28 | 47 | 20 | 5 | 30 | 32 | | 35 | 30 | 73 | T. | − 0.8 | 0 | 9,135 | s. | 42 | n. | 28 | 18 | 7 | 6 | 3.9 | T. | .... |
| Oklahoma | 1,214 | 10 | 47 | 28.71 | 30.02 | − .09 | 45.4 | +10.7 | 77 | 15 | 56 | 19 | 30 | 34 | 41 | | 37 | 30 | 65 | 0.05 | − 1.3 | 2 | 11,271 | s. | 48 | n. | 29 | 13 | 9 | 9 | 4.5 | T. | .... |
| *Southern Slope.* | | | | | | | **49.8** | **+ 8.3** | | | | | | | | | | | **54** | **0.05** | **− 0.9** | | | | | | | | **3.4** | | |
| Abilene | 1,738 | 10 | 52 | 28.22 | 30.06 | − .03 | 52.4 | + 9.8 | 82 | 27 | 65 | 20 | 30 | 40 | 38 | | 41 | 30 | 51 | T. | − 0.9 | 0 | 8,283 | sw. | 32 | sw. | 22 | 14 | 10 | 7 | 4.4 | ..... | ..... |
| Amarillo | 3,676 | 10 | 49 | 26.23 | 30.01 | − .05 | 45.4 | +11.5 | 77 | 26 | 58 | 20 | 30 | 32 | 38 | | 36 | 29 | 62 | 0.06 | − 0.5 | 2 | 7,446 | w. | 42 | w. | 28 | 23 | 7 | 1 | 3.1 | 0.6 | ..... |
| Del Rio | 944 | 8 | 57 | 29.08 | 30.09 | + .03 | 54.4 | + 4.2 | 83 | 9 | 69 | 29 | 30 | 40 | 44 | | ..... | ..... | ..... | 0.11 | − 1.6 | 1 | 4,729 | e. | 35 | w. | 23 | 22 | 8 | 1 | 2.3 | ..... | ..... |
| Roswell | 3,566 | 75 | 85 | 26.39 | 30.03 | − .01 | 47.0 | + 7.8 | 80 | 26 | 63 | 15 | 30 | 31 | 52 | | 37 | 25 | 48 | 0.04 | − 0.5 | 1 | 6,152 | nw. | 39 | sw. | 27 | 16 | 11 | 4 | 4.0 | 0.6 | .... |
| *Southern Plateau.* | | | | | | | **44.1** | **+ 3.4** | | | | | | | | | | | **59** | **1.57** | **+ 0.8** | | | | | | | | **4.1** | | |
| El Paso | 3,762 | 110 | 133 | 26.25 | 30.07 | + .06 | 48.4 | + 4.3 | 76 | 26 | 61 | 20 | 30 | 35 | 40 | | 38 | 24 | 43 | 0.03 | − 0.5 | 1 | 8,197 | w. | 50 | sw. | 28 | 17 | 12 | 2 | 3.0 | ..... | ..... |
| Santa Fe | 7,013 | 57 | 62 | 23.24 | 30.12 | + .08 | 33.5 | + 5.0 | 55 | 14 | 43 | 5 | 29 | 24 | 27 | | 26 | 19 | 59 | 0.19 | − 0.4 | 7 | 4,979 | n. | 36 | sw. | 27 | 12 | 14 | 5 | 4.5 | 0.6 | ..... |
| Flagstaff | 6,907 | 8 | 57 | ..... | ..... | ..... | 31.6 | + 4.9 | 65 | 7 | 42 | − 1 | 31 | 22 | 48 | | ..... | ..... | ..... | 2.45 | ..... | 7 | ..... | w. | 40 | w. | 27 | 14 | 7 | 10 | ..... | 13.0 | 5.0 |
| Phoenix | 1,108 | 76 | 81 | 28.88 | 30.05 | + .02 | 54.8 | + 4.8 | 77 | 7 | 67 | 35 | 29 | 43 | 34 | | 47 | 39 | 59 | 0.30 | − 0.9 | 5 | 4,051 | e. | 31 | sw. | 27 | 13 | 6 | 12 | 4.8 | ..... | ..... |
| Yuma | 141 | 9 | 58 | 29.90 | 30.05 | .00 | 57.8 | + 3.1 | 79 | 6 | 70 | 37 | 8 | 45 | 39 | | 47 | 35 | 49 | 0.05 | − 0.4 | 1 | 4,734 | n. | 30 | w. | 27 | 21 | 6 | 4 | 2.6 | ..... | ..... |
| Independence | 3,910 | 11 | 42 | 26.03 | 30.08 | + .01 | 38.6 | − 1.9 | 57 | 4 | 48 | 17 | 11 | 29 | 29 | | 35 | 33 | 86 | 7.29 | + 6.4 | 11 | 3,782 | n. | 50 | sw. | 25 | 10 | 11 | 10 | 5.5 | ..... | ..... |
| *Middle Plateau.* | | | | | | | **31.1** | **+ 3.3** | | | | | | | | | | | **75** | **2.70** | **+ 1.6** | | | | | | | | **6.1** | | |
| Reno | 4,532 | 74 | 81 | 25.40 | 30.01 | − .12 | 35.4 | + 2.9 | 63 | 6 | 45 | 11 | 28 | 26 | 36 | | 31 | 26 | 72 | 5.46 | + 3.5 | 14 | 5,033 | w. | 46 | se. | 17 | 8 | 11 | 12 | 5.8 | 22.3 | T. |
| Tonopah | 6,090 | 12 | 20 | 24.02 | 30.04 | ..... | 34.2 | ..... | 52 | 5 | 40 | 14 | 28 | 20 | 17 | | 31 | 27 | 76 | 1.11 | + 0.4 | 7 | 8,573 | se. | 50 | se. | 17 | 11 | 12 | 8 | 5.2 | 2.5 | .... |
| Winnemucca | 4,344 | 18 | 56 | 25.57 | 30.06 | − .14 | 34.6 | + 5.8 | 53 | 24 | 43 | 14 | 10 | 26 | 25 | | 31 | 27 | 79 | 1.99 | + 1.0 | 16 | 5,831 | sw. | 45 | s. | 25 | 8 | 5 | 18 | 6.8 | 3.5 | .... |
| Modena | 5,479 | 10 | 43 | 24.61 | 30.02 | − .04 | 32.2 | + 4.7 | 56 | 7 | 42 | 1 | 28 | 23 | 39 | | 28 | 22 | 70 | 1.42 | + 0.7 | 10 | 8,082 | sw. | 54 | s. | 25 | 8 | 11 | 12 | 6.1 | 5.4 | 1.7 |
| Salt Lake City | 4,360 | 147 | 189 | 25.61 | 30.06 | − .09 | 35.2 | + 6.4 | 55 | 17 | 42 | 12 | 29 | 28 | 24 | | 31 | 27 | 75 | 3.08 | + 1.7 | 12 | 5,507 | s. | 49 | nw. | 18 | 10 | 9 | 12 | 5.7 | 13.0 | 3.0 |
| Durango | 6,546 | 18 | 56 | 23.66 | 30.18 | + .13 | 25.1 | + 0.6 | 50 | 14 | 38 | − 5 | 6 | 13 | 45 | | 20 | 15 | 68 | 4.74 | + 3.5 | 12 | 3,313 | nw. | 27 | ne. | 1 | 12 | 3 | 16 | 6.2 | 55.0 | 10.0 |
| Grand Junction | 4,602 | 43 | 51 | 25.45 | 30.15 | + .03 | 24.2 | − 0.5 | 58 | 18 | 33 | − 8 | 12 | 15 | 30 | | 22 | 20 | 85 | 1.13 | + 0.6 | 12 | 2,548 | nw. | 19 | se. | 27 | 6 | 9 | 16 | 6.7 | 6.5 | .... |
| *Northern Plateau.* | | | | | | | **37.2** | **+ 8.4** | | | | | | | | | | | **69** | **2.02** | **+ 0.4** | | | | | | | | **8.0** | | |
| Baker | 3,471 | 48 | 53 | 26.33 | 29.96 | − .20 | 32.0 | + 8.1 | 45 | 6 | 38 | 16 | 19 | 26 | 20 | | 30 | 25 | 75 | 1.73 | + 0.4 | 16 | 6,144 | se. | 49 | sw. | 26 | 4 | 9 | 18 | 7.0 | 14.3 | 1.6 |
| Boise | 2,739 | 78 | 86 | 27.12 | 30.02 | − .17 | 37.8 | + 8.5 | 56 | 17 | 45 | 19 | 11 | 31 | 27 | | 34 | 27 | 63 | 1.06 | − 0.8 | 14 | 5,428 | se. | 33 | w. | 24 | 2 | 4 | 25 | 8.5 | 1.0 | 0.4 |
| Lewiston | 757 | 40 | 48 | 29.05 | 29.88 | − .28 | 40.0 | + 5.5 | 59 | 17 | 46 | 29 | 28 | 34 | 26 | | ..... | ..... | ..... | 2.06 | + 0.5 | 14 | 3,249 | e. | 26 | s. | 26 | 1 | 9 | 21 | 8.3 | 1.8 | .... |
| Pocatello | 4,477 | 46 | 54 | 25.43 | 30.04 | − .16 | 31.6 | + 6.5 | 49 | 17 | 39 | 7 | 11 | 24 | 30 | | 28 | 24 | 74 | 2.58 | + 1.9 | 17 | 8,630 | se. | 46 | sw. | 24 | 4 | 10 | 17 | 7.4 | 10.8 | 0.5 |
| Spokane | 1,929 | 101 | 110 | 27.78 | 29.85 | − .27 | 36.2 | + 9.5 | 53 | 6 | 41 | 21 | 28 | 31 | 15 | | 34 | 30 | 76 | 2.08 | − 0.2 | 13 | 5,674 | sw. | 36 | w. | 22 | 1 | 8 | 22 | 8.6 | 4.3 | T. |
| Walla Walla | 1,000 | 107 | 115 | 28.78 | 29.86 | + .19 | 45.6 | +12.4 | 70 | 6 | 52 | 27 | 24 | 39 | 27 | | 39 | 30 | 58 | 2.62 | + 0.6 | 13 | 8,761 | sw. | 44 | sw. | 26 | 1 | 6 | 24 | 8.5 | 4.0 | .... |
| *North Pacific Coast Region.* | | | | | | | **43.5** | **+ 4.0** | | | | | | | | | | | **88** | **12.64** | **+ 5.9** | | | | | | | | **8.9** | | |
| North Head | 211 | 11 | 56 | 29.52 | 29.75 | − .30 | 44.8 | + 3.0 | 55 | 11 | 48 | 34 | 27 | 42 | 11 | | 44 | 42 | 91 | 15.25 | + 8.6 | 29 | 21,383 | se. | 92 | se. | 17 | 0 | 1 | 30 | 9.7 | ..... | ..... |
| Port Crescent | 259 | 8 | 53 | 29.42 | 29.70 | − .29 | 39.1 | + 3.1 | 52 | 11 | 44 | 29 | 9 | 34 | 16 | | ..... | ..... | ..... | 14.12 | + 8.6 | 29 | 3,822 | se. | 26 | ne. | 14 | 0 | 7 | 24 | 9.0 | 6.8 | .... |
| Seattle | 125 | 215 | 250 | 29.65 | 29.78 | − .27 | 43.2 | + 3.9 | 59 | 5 | 48 | 31 | 28 | 39 | 16 | | 42 | 40 | 88 | 9.82 | + 5.3 | 26 | 9,452 | se. | 57 | sw. | 26 | 0 | 5 | 26 | 9.0 | 0.7 | .... |
| Tacoma | 213 | 113 | 120 | 29.54 | 29.78 | − .26 | 43.2 | + 5.2 | 61 | 5 | 48 | 30 | 24 | 38 | 18 | | 43 | 42 | 95 | 11.51 | + 5.7 | 27 | 5,483 | sw. | 40 | sw. | 7 | 0 | 5 | 26 | 8.9 | 0.5 | .... |
| Tatoosh Island | 86 | 7 | 57 | 29.57 | 29.67 | − .31 | 42.8 | + 1.6 | 54 | 11 | 46 | 32 | 27 | 39 | 14 | | 42 | 41 | 94 | 19.09 | + 6.9 | 30 | 16,472 | e. | 84 | s. | 2 | 0 | 7 | 24 | 9.0 | 6.0 | .... |
| Portland, Oreg | 153 | 68 | 106 | 29.65 | 29.81 | − .27 | 45.8 | + 6.7 | 62 | 5 | 50 | 33 | 27 | 41 | 15 | | 43 | 40 | 83 | 11.53 | + 5.0 | 29 | 5,877 | s. | 39 | sw. | 26 | 0 | 3 | 28 | 9.3 | 1.5 | .... |
| Roseburg | 510 | 9 | 57 | 29.32 | 29.87 | − .23 | 45.4 | + 4.6 | 68 | 5 | 52 | 32 | 11 | 39 | 27 | | 42 | 39 | 79 | 7.19 | + 1.5 | 25 | 3,090 | s. | 28 | se. | 2 | 0 | 17 | 14 | 7.6 | 0.7 | .... |
| *Middle Pacific Coast Region.* | | | | | | | **48.8** | **+ 1.5** | | | | | | | | | | | **84** | **8.16** | **+ 3.5** | | | | | | | | **6.5** | | |
| Eureka | 62 | 73 | 89 | 29.88 | 29.95 | − .15 | 49.6 | + 2.7 | 67 | 4 | 55 | 35 | 9 | 44 | 18 | | 47 | 43 | 79 | 9.75 | + 2.1 | 23 | 8,717 | s. | 59 | sw. | 25 | 0 | 8 | 23 | 8.5 | ..... | ..... |
| Mount Tamalpais | 2,375 | 11 | 18 | 27.53 | 30.02 | − .09 | 43.8 | − 2.1 | 59 | 5 | 47 | 32 | 27 | 40 | 13 | | 42 | 40 | 87 | 8.07 | + 2.1 | 20 | 17,028 | sw. | 70 | nw. | 28 | 11 | 5 | 15 | 6.2 | ..... | ..... |
| Point Reyes Light | 490 | 7 | 18 | 29.47 | 29.99 | ..... | 50.4 | + 1.0 | 63 | 5 | 54 | 41 | 27 | 47 | 11 | | ..... | ..... | ..... | 6.62 | ..... | 18 | 19,275 | s. | 84 | s. | 16 | 10 | 4 | 17 | 6.5 | ..... | ..... |
| Red Bluff | 332 | 50 | 56 | 29.65 | 30.01 | − .11 | 47.3 | + 1.9 | 64 | 31 | 53 | 30 | 11 | 42 | 24 | | 45 | 42 | 84 | 9.20 | + 5.3 | 19 | 5,828 | se. | 31 | se. | 25 | 9 | 7 | 15 | 6.4 | ..... | ..... |
| Sacramento | 69 | 106 | 117 | 29.98 | 30.05 | − .07 | 48.8 | + 3.2 | 62 | 4 | 54 | 34 | 11 | 44 | 18 | | 46 | 44 | 83 | 5.97 | + 2.3 | 16 | 7,805 | se. | 45 | se. | 16 | 8 | 6 | 17 | 6.0 | ..... | ..... |
| San Francisco | 155 | 200 | 204 | 29.87 | 30.04 | − .07 | 51.5 | + 2.0 | 63 | 3 | 56 | 42 | 16 | 47 | 18 | | 49 | 46 | 85 | 9.76 | + 5.6 | 16 | 6,408 | s. | 43 | sw. | 24 | 12 | 3 | 16 | 5.7 | ..... | ..... |
| San Jose | 141 | 12 | 110 | 29.92 | 30.06 | ..... | 50.1 | + 1.8 | 70 | 3 | 58 | 30 | 11 | 42 | 29 | | ..... | ..... | ..... | 6.23 | + 3.4 | 17 | 6,358 | se. | 44 | e. | 16 | 8 | 7 | 16 | 6.0 | ..... | ..... |
| *South Pacific Coast Region.* | | | | | | | **53.9** | **+ 3.0** | | | | | | | | | | | **75** | **8.48** | **+ 5.7** | | | | | | | | **6.0** | | |
| Fresno | 327 | 89 | 98 | 29.73 | 30.10 | .00 | 50.0 | + 4.6 | 66 | 1 | 56 | 31 | 11 | 44 | 22 | | 47 | 44 | 82 | 4.94 | + 3.3 | 13 | 5,237 | nw. | 40 | se. | 17 | 6 | 3 | 22 | 7.5 | ..... | ..... |
| Los Angeles | 338 | 159 | 191 | 29.70 | 30.07 | − .01 | 56.8 | + 3.7 | 82 | 6 | 64 | 42 | 28 | 49 | 27 | | 50 | 43 | 68 | 10.35 | + 7.5 | 10 | 4,929 | ne. | 27 | se. | 17 | 10 | 7 | 14 | 5.7 | ..... | ..... |
| San Diego | 87 | 62 | 70 | 29.97 | 30.06 | − .01 | 56.3 | + 2.3 | 76 | 6 | 63 | 42 | 29 | 50 | 24 | | 50 | 45 | 71 | 3.59 | + 1.6 | 8 | 4,989 | nw. | 40 | se. | 26 | 15 | 4 | 12 | 4.8 | ..... | ..... |
| San Luis Obispo | 201 | 47 | 54 | 29.88 | 30.10 | + .01 | 52.6 | + 1.6 | 75 | 6 | 60 | 32 | 11 | 46 | 35 | | 49 | 46 | 80 | 15.03 | +10.3 | 17 | 4,933 | n. | 36 | se. | 17 | 9 | 9 | 13 | 5.9 | ..... | ..... |
| *West Indies.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| San Juan | 82 | 8 | 54 | 29.94 | 30.03 | + .03 | 74.6 | ..... | 86 | 10 | 81 | 64 | 18 | 68 | 19 | | ..... | ..... | ..... | 1.83 | − 2.8 | 13 | 7,865 | se. | 37 | e. | 29 | 18 | 11 | 2 | 3.5 | ..... | ..... |
| *Panama.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ancon | 92 | 6 | 69 | 29.78 | 29.87 | ..... | 80.4 | ..... | 93 | 30 | 90 | 68 | 20 | 71 | 24 | | 73 | 71 | 85 | 0.32 | − 0.6 | 7 | 6,033 | nw. | 23 | n. | 8 | 19 | 11 | 1 | 3.6 | ..... | ..... |
| Culebra | 404 | 5 | 62 | 29.46 | 29.88 | ..... | 78.7 | ..... | 90 | 24 | 87 | 67 | 19 | 70 | 22 | | 72 | 71 | 89 | 0.38 | − 1.3 | 7 | 6,689 | nw. | 25 | nw. | 6 | 8 | 20 | 3 | 4.9 | ..... | ..... |
| Colon | 10 | 5 | 71 | 29.90 | 29.91 | ..... | 80.7 | ..... | 87 | 10 | 84 | 73 | 29 | 77 | 12 | | 75 | 73 | 81 | 1.35 | − 2.6 | 14 | 9,680 | n. | 32 | ne. | 15 | 13 | 12 | 6 | 4.6 | ..... | ..... |

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during January, 1914, at all stations furnished with self-registering gages.*

| Stations. | Date. | Total duration. | | Total amount of precipitation. | Excessive rate. | | Amount before excessive rate began. | Depths of precipitation (in inches) during periods of time indicated. | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | From— | To— | | Began— | Ended— | | 5 min. | 10 min. | 15 min. | 20 min. | 25 min. | 30 min. | 35 min. | 40 min. | 45 min. | 50 min. | 60 min. | 80 min. | 100 min. | 120 min. |
| Abilene, Tex | 12 | | | T. | | | | | | | | | | | | | | T. | | | |
| Albany, N. Y | 31 | | | 0.54 | | | | | | | | | | | | | | .11 | | | |
| Alpena, Mich | 31 | | | 0.88† | | | | | | | | | | | | | | (*) | | | |
| Amarillo, Tex | 4 | | | 0.04 | | | * | | | | | | | | | | | (*) | | | |
| Anniston, Ala | 30 | | | 1.53 | | | | | | | | | | | | | | .53 | | | |
| Asheville, N. C | 31 | | | 0.18 | | | | | | | | | | | | | | .08 | | | |
| Atlanta, Ga | 24 | | | 0.26 | | | | | | | | | | | | | | .24 | | | |
| Atlantic City, N. J | 24 | | | 0.99 | | | | | | | | | | | | | | .27 | | | |
| Augusta, Ga | 2 | | | 1.40 | | | | | | | | | | | | | | .35 | | | |
| Baker, Oreg | 18 | | | 0.48 | | | | | | | | | | | | | | (*) | | | |
| Baltimore, Md | 31 | | | 1.54 | | | | | | | | | | | | | | .65 | | | |
| Bentonville, Ark | 29 | | | 1.90 | | | | | | | | | | | | | | .45 | | | |
| Binghamton, N. Y | 31 | | | 0.77 | | | | | | | | | | | | | | .18 | | | |
| Birmingham, Ala | 30 | 3.35 p. m. | 10.00 p. m. | 1.01 | 5.13 p. m. | 5.48 p. m. | .03 | .21 | .23 | .29 | .38 | .46 | .52 | .57 | | | | | | | |
| Bismarck, N. Dak | 25–26 | | | 0.11 | | | | | | | | | | | | | | (*) | | | |
| Block Island, R. I | 31 | | | 0.64 | | | | | | | | | | | | | | .31 | | | |
| Boise, Idaho | 22 | | | 0.16 | | | | | | | | | | | | | | .13 | | | |
| Boston, Mass | 31 | | | 1.02 | | | | | | | | | | | | | | .35 | | | |
| Buffalo, N. Y | 3–4 | | | 1.29 | | | | | | | | | | | | | | (*) | | | |
| Burlington, Vt | 31 | | | 0.40 | | | | | | | | | | | | | | (*) | | | |
| Cairo, Ill | 23–24 | | | 0.71 | | | | | | | | | | | | | | .31 | | | |
| Canton, N. Y | 10 | | | 0.32 | | | | | | | | | | | | | | (*) | | | |
| Charles City, Iowa | 28 | | | 0.59 | | | | | | | | | | | | | | (*) | | | |
| Charleston, S. C | 23–24 | | | 1.36 | | | | | | | | | | | | | | .55 | | | |
| Charlotte, N. C | 30 | | | 0.66 | | | | | | | | | | | | | | .32 | | | |
| Chattanooga, Tenn | 30 | | | 3.10 | | | | | | | | | | | | | | .65 | | | |
| Cheyenne, Wyo | 26 | | | 0.06 | | | | | | | | | | | | | | (*) | | | |
| Chicago, Ill | 31 | | | 1.52 | | | | | | | | | | | | | | (*) | | | |
| Cincinnati, Ohio | 31 | | | 0.71 | | | | | | | | | | | | | | .17 | | | |
| Cleveland, Ohio | 2–3 | | | 0.60 | | | | | | | | | | | | | | (*) | | | |
| Columbia, Mo | 28–29 | | | 0.35 | | | | | | | | | | | | | | (*) | | | |
| Columbia, S. C | 24 | | | 0.75 | | | | | | | | | | | | | | .44 | | | |
| Columbus, Ohio | 31 | | | 0.53 | | | | | | | | | | | | | | .13 | | | |
| Concord, N. H | 24–25 | | | 0.90 | | | | | | | | | | | | | | (*) | | | |
| Concordia, Kans | 10 | | | 0.11 | | | | | | | | | | | | | | (*) | | | |
| Corpus Christi, Tex | 29 | | | 0.08 | | | | | | | | | | | | | | .03 | | | |
| Davenport, Iowa | 28–29 | | | 0.44 | | | | | | | | | | | | | | (*) | | | |
| Dayton, Ohio | 30–31 | | | 1.18 | | | | | | | | | | | | | | (*) | | | |
| Del Rio, Tex | 12 | | | 0.11 | | | | | | | | | | | | | | .05 | | | |
| Denver, Colo | 9 | | | 0.01 | | | | | | | | | | | | | | .01 | | | |
| Des Moines, Iowa | 28 | | | 0.21† | | | | | | | | | | | | | | .06 | | | |
| Detroit, Mich | 31 | | | 1.32 | | | | | | | | | | | | | | (*) | | | |
| Devils Lake, N. Dak | 28 | | | 0.21 | | | | | | | | | | | | | | (*) | | | |
| Dodge City, Kans | 10 | | | 0.18 | | | | | | | | | | | | | | (*) | | | |
| Dubuque, Iowa | 18 | | | 0.35 | | | | | | | | | | | | | | (*) | | | |
| Duluth, Minn | 1–2 | | | 0.64 | | | | | | | | | | | | | | (*) | | | |
| Durango, Colo | 16–17 | | | 1.65 | | | | | | | | | | | | | | (*) | | | |
| Eastport, Me | 24–25 | | | 1.38 | | | | | | | | | | | | | | .28 | | | |
| Elkins, W. Va | 3–4 | | | 0.49† | | | | | | | | | | | | | | (*) | | | |
| El Paso, Tex | 17 | | | 0.03 | | | | | | | | | | | | | | .02 | | | |
| Erie, Pa | 3–4 | | | 1.92† | | | | | | | | | | | | | | (*) | | | |
| Escanaba, Mich | 26 | | | 0.33 | | | | | | | | | | | | | | (*) | | | |
| Eureka, Cal | 16 | | | 0.95 | | | | | | | | | | | | | | .38 | | | |
| Evansville, Ind | 30 | | | 1.06 | | | | | | | | | | | | | | .22 | | | |
| Flagstaff, Ariz | 26–27 | | | 1.53† | | | | | | | | | | | | | | (*) | | | |
| Fort Smith, Ark | 29 | | | 0.90 | | | | | | | | | | | | | | .11 | | | |
| Fort Wayne, Ind | 30–31 | | | 0.98 | | | | | | | | | | | | | | (*) | | | |
| Fort Worth, Tex | 28 | | | 0.29 | | | | | | | | | | | | | | .22 | | | |
| Fresno, Cal | 25 | | | 1.61 | | | | | | | | | | | | | | .57 | | | |
| Galveston, Tex | 29 | | | 0.22 | | | | | | | | | | | | | | .13 | | | |
| Grand Haven, Mich | 31 | | | 1.05† | | | | | | | | | | | | | | (*) | | | |
| Grand Junction, Colo | 16–17 | | | 0.40† | | | | | | | | | | | | | | (*) | | | |
| Grand Rapids, Mich | 31 | | | 1.39 | | | | | | | | | | | | | | (*) | | | |
| Green Bay, Wis | 28–29 | | | 0.32 | | | | | | | | | | | | | | (*) | | | |
| Hannibal, Mo | 29 | | | 0.41 | | | | | | | | | | | | | | (*) | | | |
| Harrisburg, Pa | 31 | | | 0.74 | | | | | | | | | | | | | | .15 | | | |
| Hartford, Conn | 31 | | | 1.61 | | | | | | | | | | | | | | .37 | | | |
| Hatteras, N. C | 3 | 1.15 a. m. | 10.17 a. m. | 1.26 | 8.07 a. m. | 8.30 a. m. | .36 | .09 | .26 | .55 | .77 | .85 | | | | | | | | | |
| Havre, Mont | 21–22 | | | 0.22 | | | | | | | | | | | | | | (*) | | | |
| Helena, Mont | 22–23 | | | 0.19 | | | | | | | | | | | | | | (*) | | | |
| Houghton, Mich | 11–12 | | | 0.70 | | | | | | | | | | | | | | (*) | | | |
| Houston, Tex | 29 | | | 0.40 | | | | | | | | | | | | | | .16 | | | |
| Huron, S. Dak | 1 | | | 0.20 | | | | | | | | | | | | | | (*) | | | |
| Independence, Cal | 25–26 | | | 3.53 | | | | | | | | | | | | | | (*) | | | |
| Indianapolis, Ind | 30–31 | | | 1.68 | | | | | | | | | | | | | | (*) | | | |
| Iola, Kans | 28 | | | 0.25 | | | | | | | | | | | | | | .22 | | | |
| Jacksonville, Fla | 24 | | | 0.93 | | | | | | | | | | | | | | .27 | | | |
| Kalispell, Mont | 21–22 | | | 0.56 | | | | | | | | | | | | | | (*) | | | |
| Kansas City, Mo | 28 | | | 0.10 | | | | | | | | | | | | | | .09 | | | |
| Keokuk, Iowa | 28–29 | | | 0.77 | | | | | | | | | | | | | | (*) | | | |
| Key West, Fla | 25 | 5.15 p. m. | 7.45 p. m. | 0.64 | 6.18 p. m. | 6.38 p. m. | .03 | .05 | .12 | .37 | .58 | | | | | | | | | | |
| Knoxville, Tenn | 2–3 | | | 0.82 | | | | | | | | | | | | | | (*) | | | |
| La Crosse, Wis | 28 | | | 0.78 | | | | | | | | | | | | | | .25 | | | |
| Lander, Wyo | 8 | | | 0.06 | | | | | | | | | | | | | | (*) | | | |
| Lansing, Mich | 31 | | | 1.07 | | | | | | | | | | | | | | (*) | | | |
| Lewiston, Idaho | 4 | | | 0.34 | | | | | | | | | | | | | | .14 | | | |
| Lexington, Ky | 30 | | | 1.01 | | | | | | | | | | | | | | .24 | | | |
| Lincoln, Nebr | 17–18 | | | 0.22 | | | | | | | | | | | | | | (*) | | | |
| Little Rock, Ark | 23 | | | 0.42 | | | | | | | | | | | | | | .41 | | | |
| Los Angeles, Cal | 17–18 | 5.05 p. m. | 10.15 a. m. | 2.47 | 5.07 a. m. | 5.21 a. m. | 1.64 | .11 | .39 | .48 | | | | | | | | | | | |
| Louisville, Ky | 30 | | | 0.60 | | | | | | | | | | | | | | .26 | | | |
| Ludington, Mich | 28–29 | | | 0.62 | | | | | | | | | | | | | | (*) | | | |
| Lynchburg, Va | 31 | | | 0.70 | | | | | | | | | | | | | | .44 | | | |
| Macon, Ga | 2 | | | 1.08 | | | | | | | | | | | | | | .38 | | | |
| Madison, Wis | 28–29 | | | 0.30 | | | | | | | | | | | | | | (*) | | | |
| Marquette, Mich | 8–9 | | | 0.58 | | | | | | | | | | | | | | (*) | | | |
| Memphis, Tenn | 24 | | | 0.65 | | | | | | | | | | | | | | .43 | | | |
| Meridian, Miss | 24 | | | 0.42 | | | | | | | | | | | | | | .34 | | | |

* Self-register not working.

† Record partly estimated.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during January, 1914, at all stations furnished with self-registering gages*—Continued.

| Stations. | Date. | Total duration. | | Total amount of precipitation. | Excessive rate. | | Amount before excessive rate began. | Depths of precipitation (in inches) during periods of time indicated. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | From— | To— | | Began— | Ended— | | 5 min. | 10 min. | 15 min. | 20 min. | 25 min. | 30 min. | 35 min. | 40 min. | 45 min. | 50 min. | 60 min. | 80 min. | 100 min. | 120 min. |
| Miami, Fla. | 3 | | | 0.25 | | | | | | | | | | | | | | .24 | | | |
| Milwaukee, Wis. | 29 | | | 0.26 | | | | | | | | | | | | | | (*) | | | |
| Minneapolis, Minn. | 1 | | | 0.42 | | | | | | | | | | | | | | (*) | | | |
| Mobile, Ala. | 2 | 10.00 a. m. | 12.20 p. m. | 1.06 | 11.00 a. m. | 11.45 a. m. | .11 | .08 | .31 | .49 | .52 | .52 | .58 | .75 | .85 | .91 | | | | | |
| Modena, Utah. | 27 | | | 0.50 | | | | | | | | | | | | | | (*) | | | |
| Montgomery, Ala. | 2 | | | 0.78 | | | | | | | | | | | | | | .39 | | | |
| Moorhead, Minn. | 22 | | | 0.14 | | | | | | | | | | | | | | (*) | | | |
| Mount Tamalpais, Cal. | 22 | | | 1.21 | | | | | | | | | | | | | | .50 | | | |
| Mount Weather, Va. | 3–4 | | | 1.67 | | | | | | | | | | | | | | (*) | | | |
| Nantucket, Mass. | 24 | | | 0.59 | | | | | | | | | | | | | | .28 | | | |
| Nashville, Tenn. | 30 | | | 1.02 | | | | | | | | | | | | | | .32 | | | |
| New Haven, Conn. | 31 | | | 2.12 | | | | | | | | | | | | | | .69 | | | |
| New Orleans, La. | 23 | | | 0.82 | | | | | | | | | | | | | | (*) | | | |
| New York, N. Y. | 31 | | | 1.89 | | | | | | | | | | | | | | .39 | | | |
| Norfolk, Va. | 3 | | | 1.26 | | | | | | | | | | | | | | .33 | | | |
| Northfield, Vt. | 31 | | | 0.62 | | | | | | | | | | | | | | (*) | | | |
| North Head, Wash. | 6 | | | 2.61 | | | | | | | | | | | | | | .28 | | | |
| North Platte, Nebr. | 28 | | | 0.09 | | | | | | | | | | | | | | (*) | | | |
| Oklahoma, Okla. | 28–29 | | | 0.05 | | | | | | | | | | | | | | .04 | | | |
| Omaha, Nebr. | 17–18 | | | 0.41 | | | | | | | | | | | | | | (*) | | | |
| Oswego, N. Y. | 31 | | | 0.62 | | | | | | | | | | | | | | (*) | | | |
| Palestine, Tex. | 29 | | | 0.52 | | | | | | | | | | | | | | .13 | | | |
| Parkersburg, W. Va. | 31 | | | 0.34 | | | | | | | | | | | | | | .13 | | | |
| Pensacola, Fla. | 23 | | | 0.91 | | | | | | | | | | | | | | .28 | | | |
| Peoria, Ill. | 23 | | | 0.50 | | | | | | | | | | | | | | .20 | | | |
| Philadelphia, Pa. | 31 | | | 0.66 | | | | | | | | | | | | | | .24 | | | |
| Phoenix, Ariz. | 27 | | | 0.19 | | | | | | | | | | | | | | .05 | | | |
| Pierre, S. Dak. | 24 | | | 0.25 | | | | | | | | | | | | | | (*) | | | |
| Pittsburgh, Pa. | 30 | | | 0.22 | | | | | | | | | | | | | | .12 | | | |
| Pocatello, Idaho. | 25 | | | 0.70 | | | | | | | | | | | | | | .35 | | | |
| Point Reyes Light, Cal. | 12 | | | 1.32 | | | | | | | | | | | | | | .29 | | | |
| Port Huron, Mich. | 31 | | | 0.76 | | | | | | | | | | | | | | (*) | | | |
| Portland, Me. | 21 | | | 1.00 | | | | | | | | | | | | | | .16 | | | |
| Portland, Oreg. | 22–23 | | | 0.99 | | | | | | | | | | | | | | .23 | | | |
| Providence, R. I. | 31 | | | 1.21 | | | | | | | | | | | | | | .39 | | | |
| Pueblo, Colo. | 28 | | | 0.12 | | | | | | | | | | | | | | (*) | | | |
| Raleigh, N. C. | 3 | | | 1.18 | | | | | | | | | | | | | | .47 | | | |
| Rapid City, S. Dak. | 22 | | | 0.00 | | | | | | | | | | | | | | (*) | | | |
| Reading, Pa. | 31 | | | 1.25 | | | | | | | | | | | | | | .39 | | | |
| Red Bluff, Cal. | 13 | | | 1.05 | | | | | | | | | | | | | | .31 | | | |
| Reno, Nev. | 17–18 | | | 1.35 | | | | | | | | | | | | | | (*) | | | |
| Richmond, Va. | 3 | | | 2.14 | | | | | | | | | | | | | | .41 | | | |
| Rochester, N. Y. | 31 | | | 0.97 | | | | | | | | | | | | | | (*) | | | |
| Roseburg, Oreg. | 24 | | | 0.82 | | | | | | | | | | | | | | .19 | | | |
| Roswell, N. Mex. | 29 | | | 0.04 | | | | | | | | | | | | | | (*) | | | |
| Sacramento, Cal. | 22 | | | 0.50 | | | | | | | | | | | | | | .26 | | | |
| Saginaw, Mich. | 31 | | | 1.56 | | | | | | | | | | | | | | (*) | | | |
| St. Joseph, Mo. | 25 | | | 0.15 | | | | | | | | | | | | | | (*) | | | |
| St. Louis, Mo. | 30–31 | | | 0.82 | | | | | | | | | | | | | | (*) | | | |
| St. Paul, Minn. | 1–2 | | | 0.47 | | | | | | | | | | | | | | (*) | | | |
| Salt Lake City, Utah. | 26 | | | 0.84 | | | | | | | | | | | | | | (*) | | | |
| San Antonio, Tex. | 29 | | | 0.05 | | | | | | | | | | | | | | .05 | | | |
| San Diego, Cal. | 26 | | | 2.04 | | | | | | | | | | | | | | .53 | | | |
| Sand Key, Fla. | 25 | | | 1.04 | | | | | | | | | | | | | | .43 | | | |
| Sandusky, Ohio. | 30–31 | | | 0.71 | | | | | | | | | | | | | | (*) | | | |
| San Francisco, Cal. | 12 | | | 1.86 | | | | | | | | | | | | | | .69 | | | |
| San Jose, Cal. | 17 | | | 0.75 | | | | | | | | | | | | | | .33 | | | |
| San Luis Obispo, Cal. | 25 | | | 4.62 | | | | | | | | | | | | | | .56 | | | |
| Santa Fe, N. Mex. | 25 | | | 0.06 | | | | | | | | | | | | | | (*) | | | |
| Sault Ste. Marie, Mich. | 8–9 | | | 0.34 | | | | | | | | | | | | | | (*) | | | |
| Savannah, Ga. | 23 | | | 1.73 | | | | | | | | | | | | | | .32 | | | |
| Scranton, Pa. | 3 | | | 0.29† | | | | | | | | | | | | | | (*) | | | |
| Seattle, Wash. | 22 | | | 0.61 | | | | | | | | | | | | | | .23 | | | |
| Sheridan, Wyo. | 24 | | | 0.22 | | | | | | | | | | | | | | (*) | | | |
| Shreveport, La. | 29 | | | 0.50 | | | | | | | | | | | | | | .24 | | | |
| Sioux City, Iowa. | 17–18 | | | 0.42 | | | | | | | | | | | | | | (*) | | | |
| Spokane, Wash. | 21 | | | 0.50 | | | | | | | | | | | | | | (*) | | | |
| Springfield, Ill. | 30–31 | | | 1.08 | | | | | | | | | | | | | | (*) | | | |
| Springfield, Mo. | 29 | | | 1.11 | | | | | | | | | | | | | | (*) | | | |
| Syracuse, N. Y. | 31 | | | 0.90 | | | | | | | | | | | | | | (*) | | | |
| Tacoma, Wash. | 22 | | | 0.78 | | | | | | | | | | | | | | .28 | | | |
| Tampa, Fla. | 23–24 | 8.30 p. m. | 6.25 a. m. | 2.97 | 1.07 a. m. | 2.11 a. m. | .59 | .11 | .19 | .32 | .45 | .59 | .66 | .72 | .77 | .88 | .97 | 1.09 | 1.25 | | |
| Tatoosh Island, Wash. | 6 | | | 0.87 | | | | | | | | | | | | | | .34 | | | |
| Taylor, Tex. | 29 | | | 0.07 | | | | | | | | | | | | | | .04 | | | |
| Terre Haute, Ind. | 30–31 | | | 1.46† | | | | | | | | | | | | | | (*) | | | |
| Thomasville, Ga. | 23 | | | 3.19 | | | | | | | | | | | | | | .75 | | | |
| Toledo, Ohio. | 30–31 | | | 1.40 | | | | | | | | | | | | | | (*) | | | |
| Tonopah, Nev. | 25–26 | | | 0.60 | | | | | | | | | | | | | | (*) | | | |
| Topeka, Kans. | 17 | | | 0.03 | | | | | | | | | | | | | | .02 | | | |
| Valentine, Nebr. | 24–25 | | | 0.04 | | | | | | | | | | | | | | (*) | | | |
| Vicksburg, Miss. | 2 | | | 0.19 | | | | | | | | | | | | | | .12 | | | |
| Walla Walla, Wash. | 22–23 | | | 0.72 | | | | | | | | | | | | | | (*) | | | |
| Washington, D. C. | 24 | | | 1.20 | | | | | | | | | | | | | | .37 | | | |
| Wichita, Kans. | 5 | | | T. | | | | | | | | | | | | | | T. | | | |
| Williston, N. Dak. | 28 | | | 0.25 | | | | | | | | | | | | | | (*) | | | |
| Wilmington, N. C. | 24 | | | 0.78 | | | | | | | | | | | | | | .27 | | | |
| Winnemucca, Nev. | 17–18 | | | 0.40 | | | | | | | | | | | | | | (*) | | | |
| Wytheville, Va. | 2–3 | | | 1.23 | | | | | | | | | | | | | | (*) | | | |
| Yankton, S. Dak. | 17 | | | 0.25 | | | | | | | | | | | | | | (*) | | | |
| Yellowstone Park, Wyo. | 25–26 | | | 0.30 | | | | | | | | | | | | | | (*) | | | |

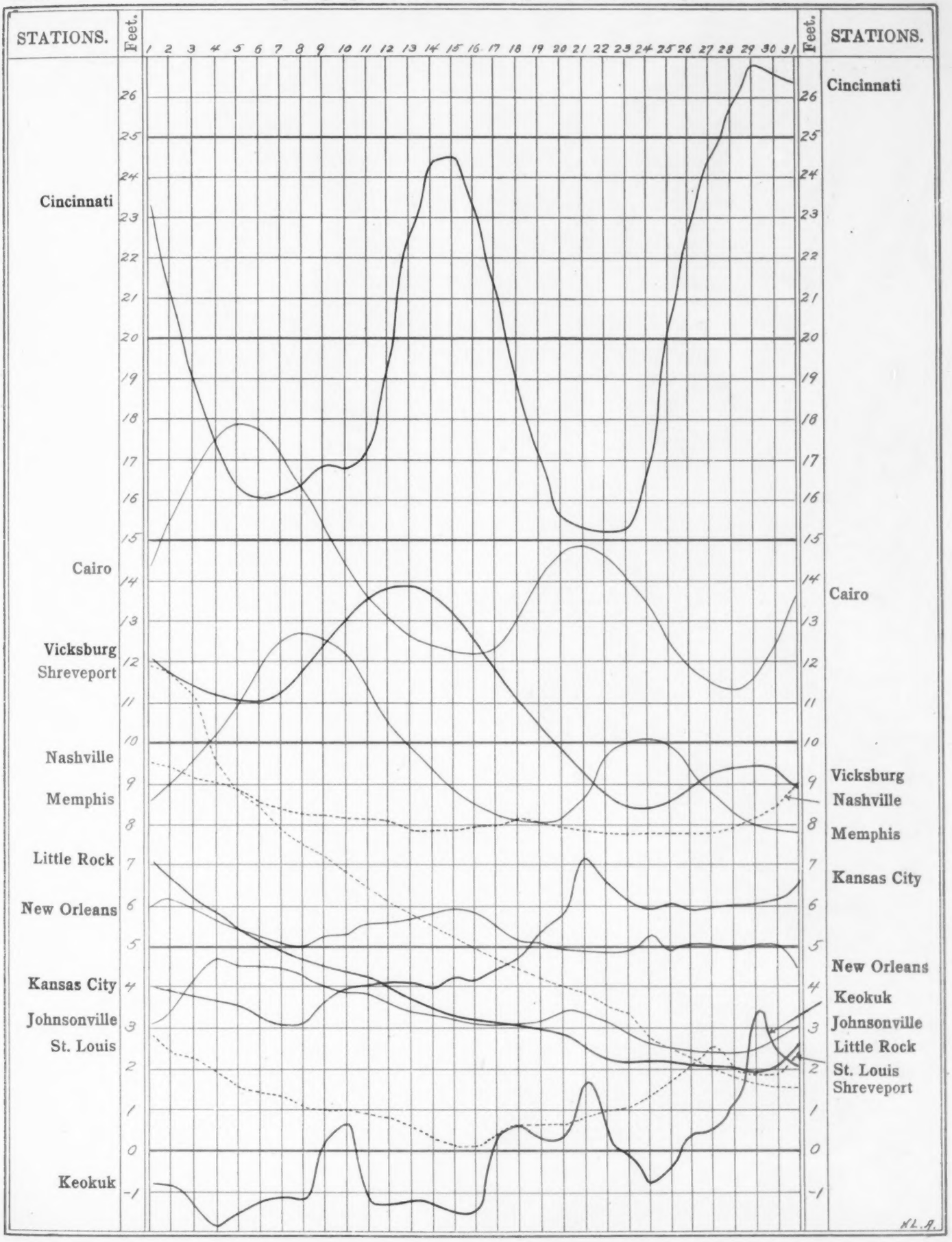
* Self-register not working.

† Record partly estimated.

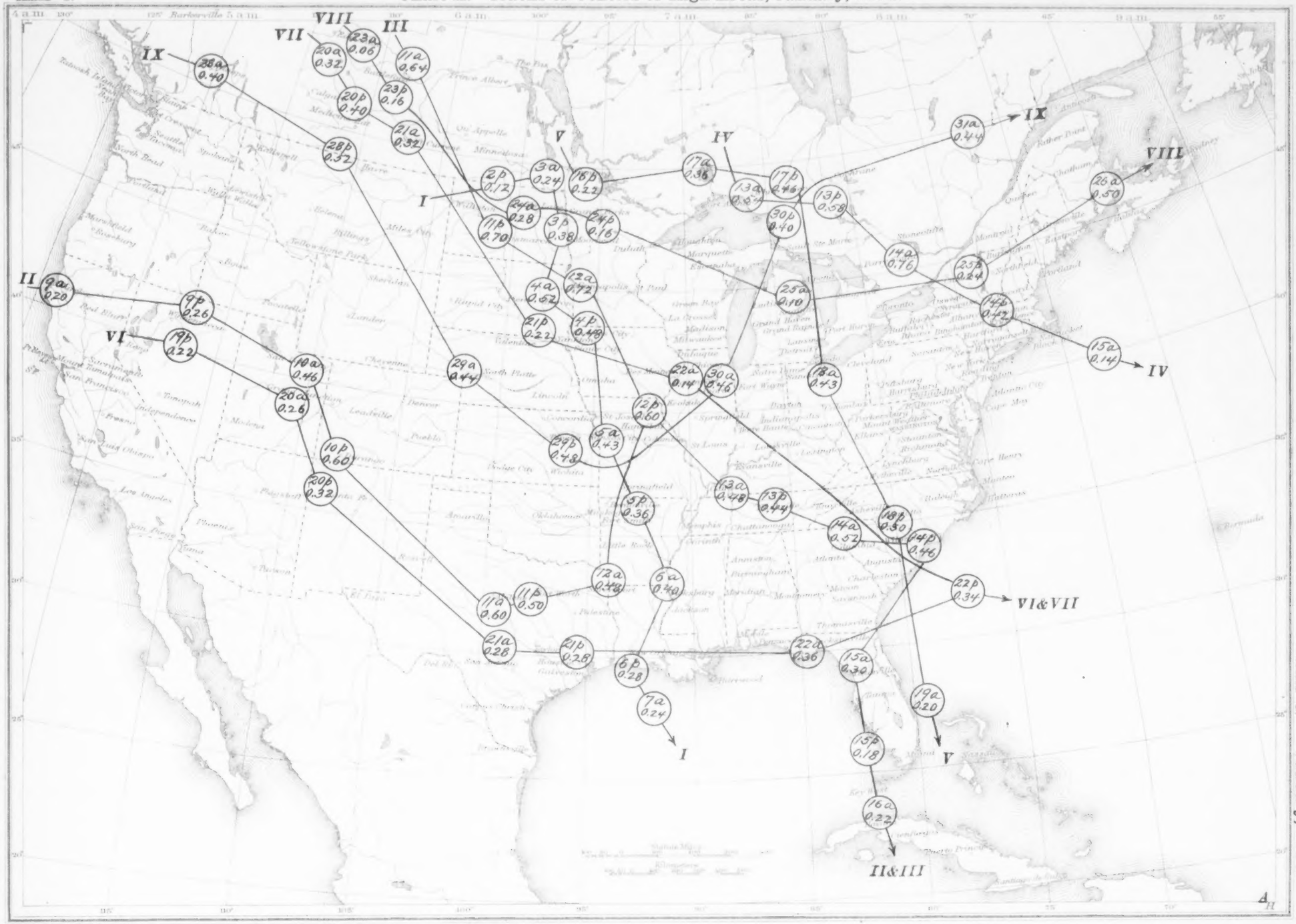
TABLE III.—*Data furnished by the Canadian Meteorological Service, January, 1914.*

| Districts and stations. | Pressure in inches. | | | Temperature. | | | | | | Precipitation. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Station reduced to mean of 24 hours. | Sea level reduced to mean of 24 hours. | Departure from normal. | Mean max.+ mean min.÷2. | Departure from normal. | Mean maximum. | Mean minimum. | Highest. | Lowest. | Total. | Departure from normal. | Snowfall. |
| St. Johns, N. F. | 29.38 | 29.52 | −0.34 | 22.6 | − 1.2 | 28.0 | 17.2 | 47 | 5 | 5.45 | −0.46 | 21.0 |
| Sydney, C. B. I. | 29.73 | 29.77 | − .16 | 22.7 | + 2.2 | 29.6 | 15.8 | 50 | 0 | 2.34 | −2.76 | 15.0 |
| Halifax, N. S. | 29.72 | 29.83 | − .14 | 22.2 | + 0.4 | 31.3 | 13.1 | 51 | − 7 | 2.86 | −2.91 | 8.9 |
| Yarmouth, N. S. | 29.79 | 29.86 | − .14 | 25.8 | − 0.5 | 33.2 | 18.4 | 45 | 1 | 3.07 | −2.34 | 12.6 |
| Charlottetown, P. E. I. | 29.79 | 29.83 | − .13 | 16.8 | − 0.2 | 24.6 | 8.9 | 42 | − 6 | 3.29 | −0.67 | 25.2 |
| Chatham, N. B. | 29.88 | 29.91 | − .06 | 10.4 | + 0.6 | 21.2 | − 0.3 | 44 | −21 | 3.66 | +0.07 | 22.3 |
| Father Point, Que. | 29.92 | 29.95 | − .03 | 7.2 | − 0.8 | 15.9 | − 1.5 | 44 | −20 | 1.01 | −1.84 | 9.5 |
| Quebec, Que. | 29.60 | 29.94 | − .08 | 10.1 | + 1.0 | 18.3 | 1.9 | 43 | −24 | 3.69 | −0.32 | 36.5 |
| Montreal, Que. | 29.73 | 29.96 | − .08 | 12.2 | + 0.5 | 20.1 | 4.3 | 44 | −27 | 4.23 | +0.50 | 31.2 |
| Stonecliffe, Ont. | 29.32 | 29.96 | − .06 | 9.1 | + 2.7 | 18.4 | − 0.2 | 47 | −32 | 3.18 | +0.86 | 31.7 |
| Ottawa, Ont. | 29.69 | 30.03 | .00 | 11.2 | + 1.6 | 20.2 | 2.1 | 42 | −30 | 3.12 | +0.13 | 25.6 |
| Kingston, Ont. | 29.63 | 29.97 | − .08 | 17.0 | − 0.1 | 26.1 | 7.8 | 45 | −28 | 2.76 | −0.69 | 21.5 |
| Toronto, Ont. | 29.50 | 29.90 | − .15 | 25.6 | + 4.2 | 33.3 | 17.8 | 54 | −22 | 3.44 | +0.52 | 30.2 |
| White River, Ont. | 28.51 | 29.89 | − .12 | 3.6 | + 4.0 | 18.0 | −10.8 | 37 | −48 | 1.09 | −0.69 | 10.0 |
| Port Stanley, Ont. | 29.26 | 29.92 | − .15 | 27.6 | + 5.4 | 34.1 | 20.2 | 47 | −11 | 3.93 | +0.94 | 32.0 |
| Southampton, Ont. | 29.17 | ..... | ..... | 24.8 | + 4.4 | 31.9 | 17.7 | 52 | −10 | 3.17 | −0.88 | 29.4 |
| Parry Sound, Ont. | 29.20 | 29.93 | − .08 | 17.6 | + 3.8 | 28.2 | 7.1 | 47 | −34 | 2.98 | −1.10 | 28.0 |
| Port Arthur, Ont. | 29.19 | 29.92 | − .15 | 12.6 | + 9.5 | 23.0 | 2.3 | 36 | −22 | 0.97 | +0.15 | 9.7 |
| Winnipeg, Man. | 29.07 | 29.94 | − .17 | 7.7 | +14.5 | 16.7 | − 1.3 | 34 | −24 | 0.79 | −0.09 | 7.8 |
| Minnedosa, Man. | 28.02 | 29.93 | − .17 | 4.2 | +11.4 | 14.3 | − 5.8 | 37 | −30 | 1.76 | +0.96 | 17.6 |
| Qu'Appelle, Sask. | 27.54 | 29.89 | − .19 | 9.5 | +13.3 | 18.2 | 0.8 | 50 | −30 | 1.54 | +1.04 | 15.4 |
| Medicine Hat, Alberta. | 27.48 | 29.85 | − .22 | 16.8 | +11.3 | 27.3 | 6.4 | 56 | −29 | 1.22 | +0.65 | 10.9 |
| Swift Current, Sask. | 27.16 | 29.85 | − .24 | 13.4 | +10.3 | 24.2 | 2.6 | 56 | −36 | 0.61 | −0.03 | 6.1 |
| Calgary, Alberta. | 26.14 | 29.80 | − .23 | 16.3 | + 7.9 | 26.0 | 6.6 | 56 | −26 | 0.93 | +0.40 | 9.3 |
| Banff, Alberta. | 25.07 | 29.84 | − .16 | 16.0 | + 3.9 | 23.4 | 8.6 | 40 | −25 | 2.54 | +1.35 | 19.1 |
| Edmonton, Alberta. | 27.47 | 29.88 | − .15 | 7.8 | + 6.0 | 16.6 | − 1.0 | 42 | −29 | 1.04 | +0.36 | 10.4 |
| Prince Albert, Sask. | 28.24 | 29.87 | − .22 | 4.7 | +13.1 | 13.7 | − 4.3 | 36 | −35 | 0.71 | −0.26 | 7.1 |
| Battleford, Sask. | 28.07 | 29.90 | − .18 | 5.8 | +11.7 | 14.5 | − 2.9 | 40 | −35 | 0.70 | +0.30 | 7.0 |
| Kamloops, B. C. | 28.49 | 29.78 | − .18 | 29.8 | + 6.8 | 35.5 | 24.2 | 50 | − 2 | 1.68 | +0.86 | 12.3 |
| Victoria, B. C. | 29.61 | 29.71 | − .26 | 42.1 | + 3.6 | 45.5 | 38.7 | 52 | 28 | 8.47 | +3.08 | 3.6 |
| Barkerville, B. C. | 25.28 | 29.67 | − .22 | 16.7 | − 1.1 | 23.7 | 9.7 | 36 | −25 | 4.60 | +2.00 | 41.5 |
| Hamilton, Bermuda. | 29.84 | 30.01 | − .12 | 62.4 | + 0.4 | 66.1 | 58.7 | 71 | 47 | 6.18 | +1.24 | ..... |

## Chart I. Hydrographs of Several Principal Rivers, January, 1914.



## Chart II. Tracks of Centers of High Areas, January, 1914.



## Chart III. Tracks of Centers of Low Areas, January, 1914.

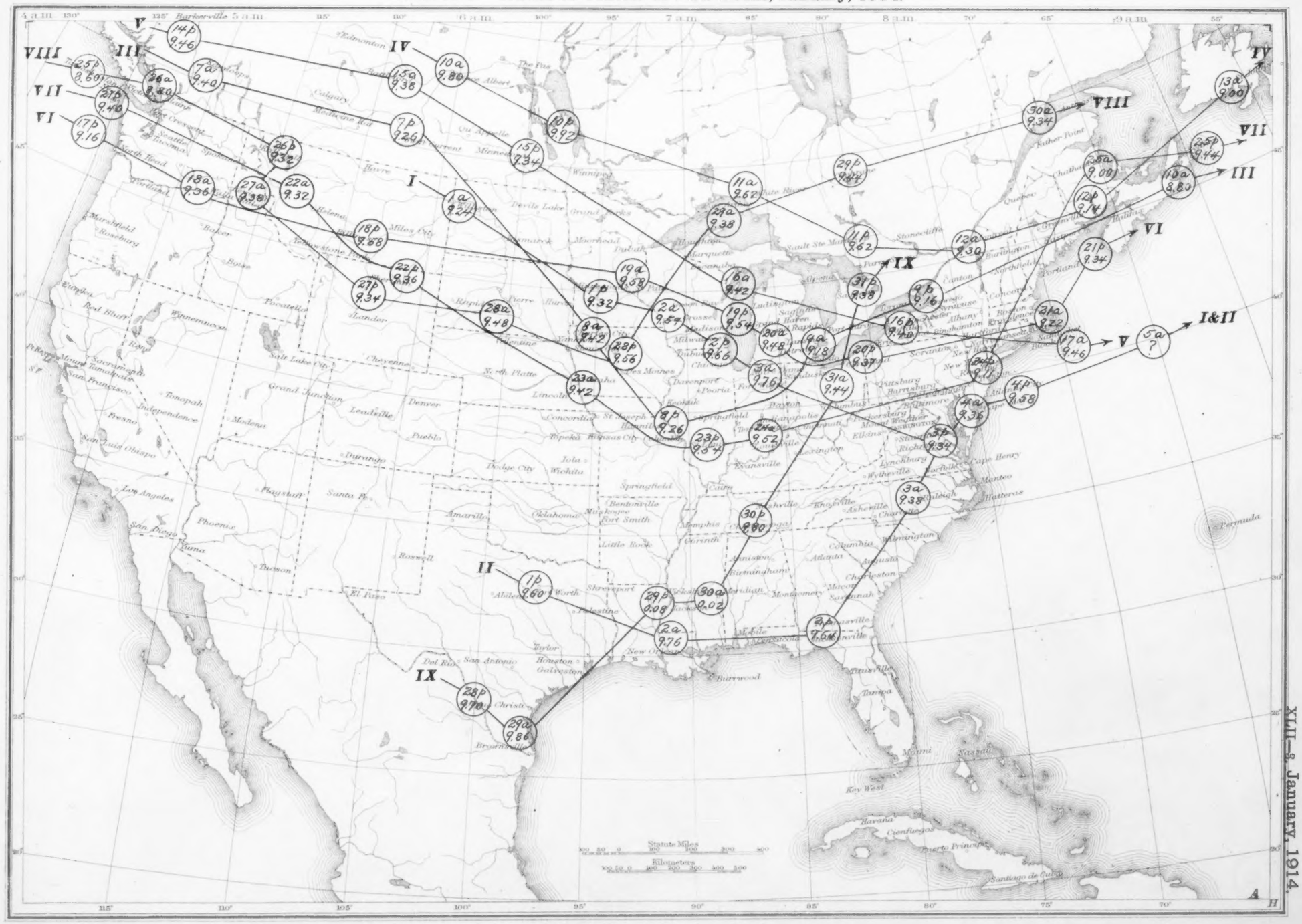
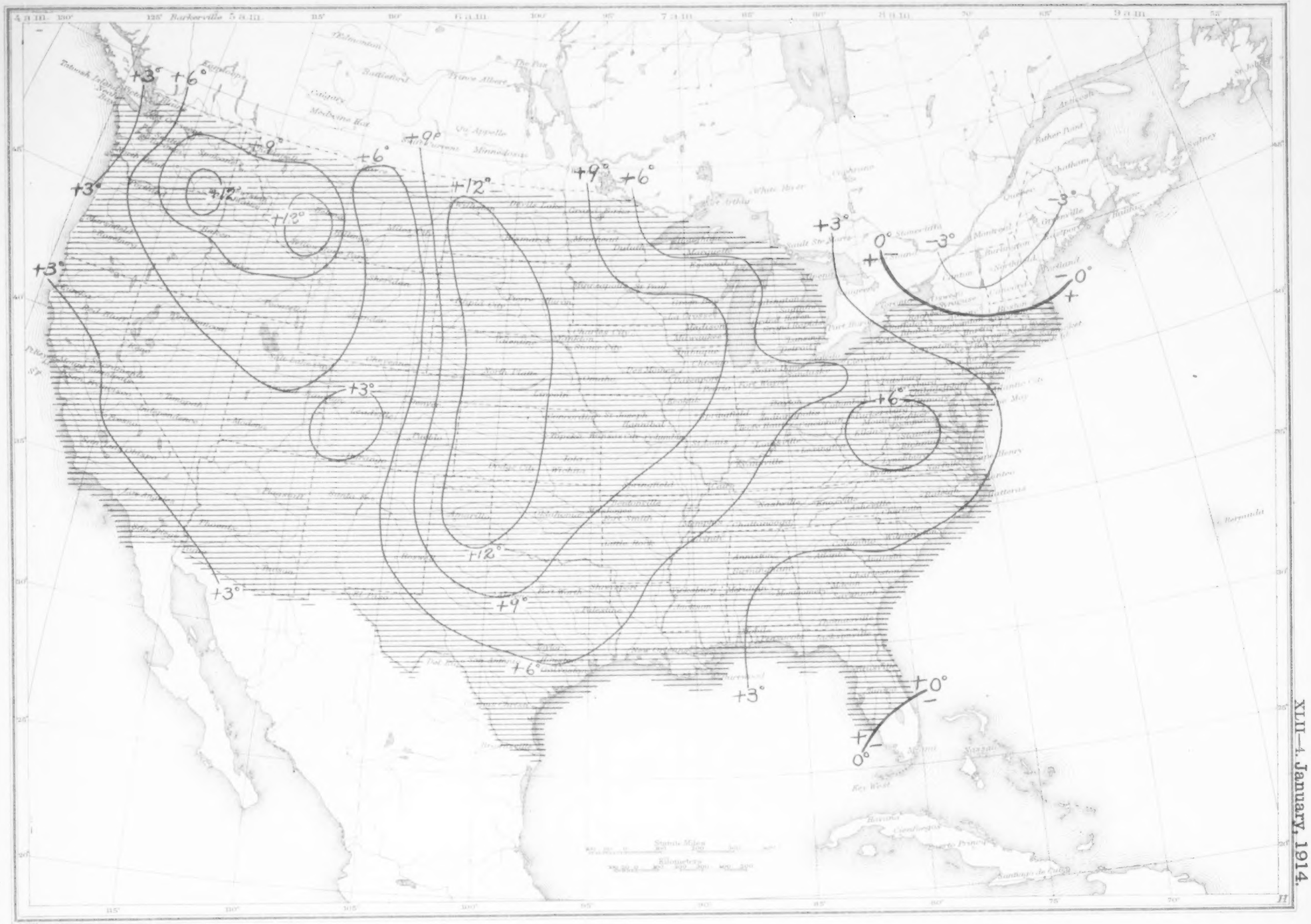
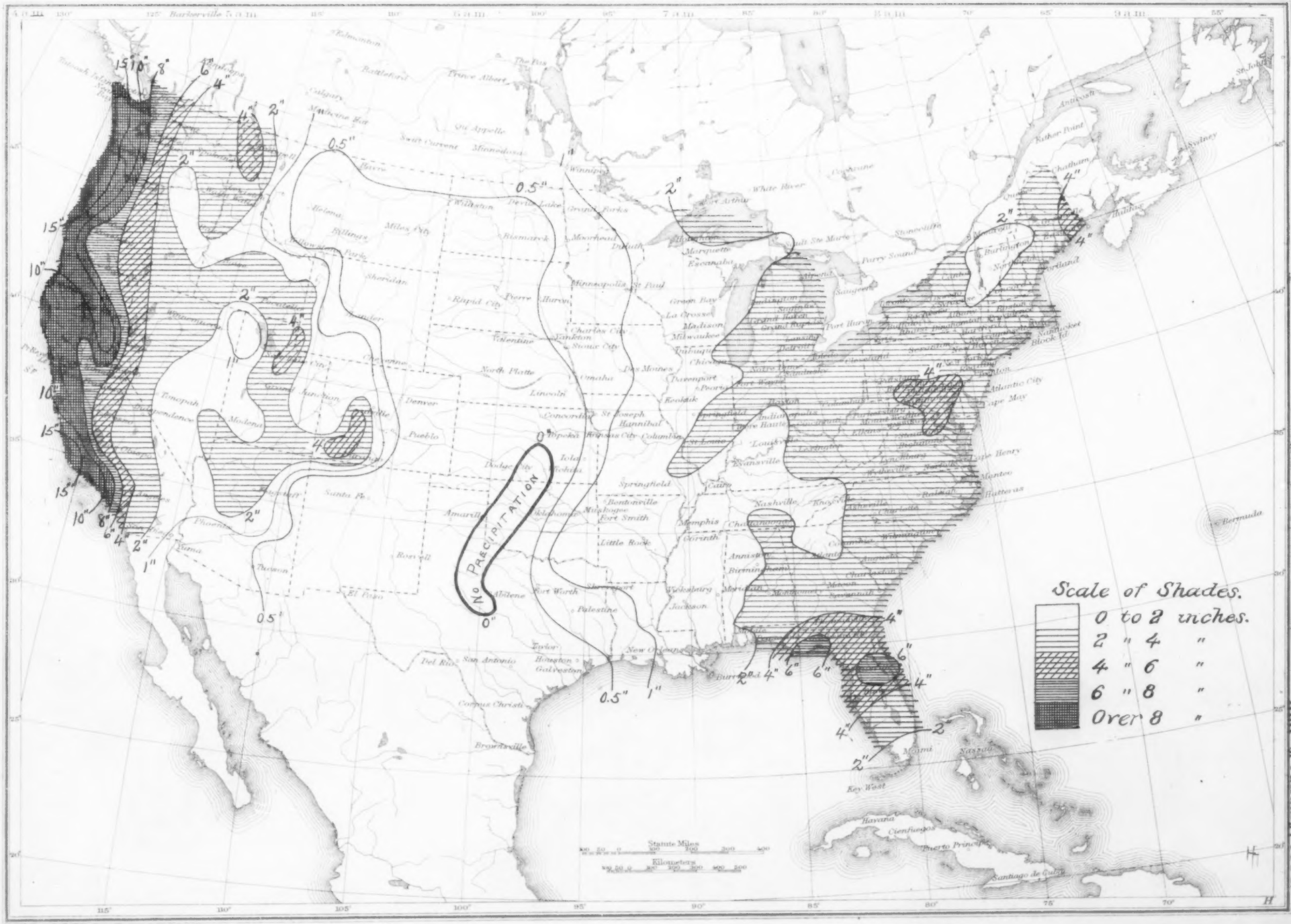


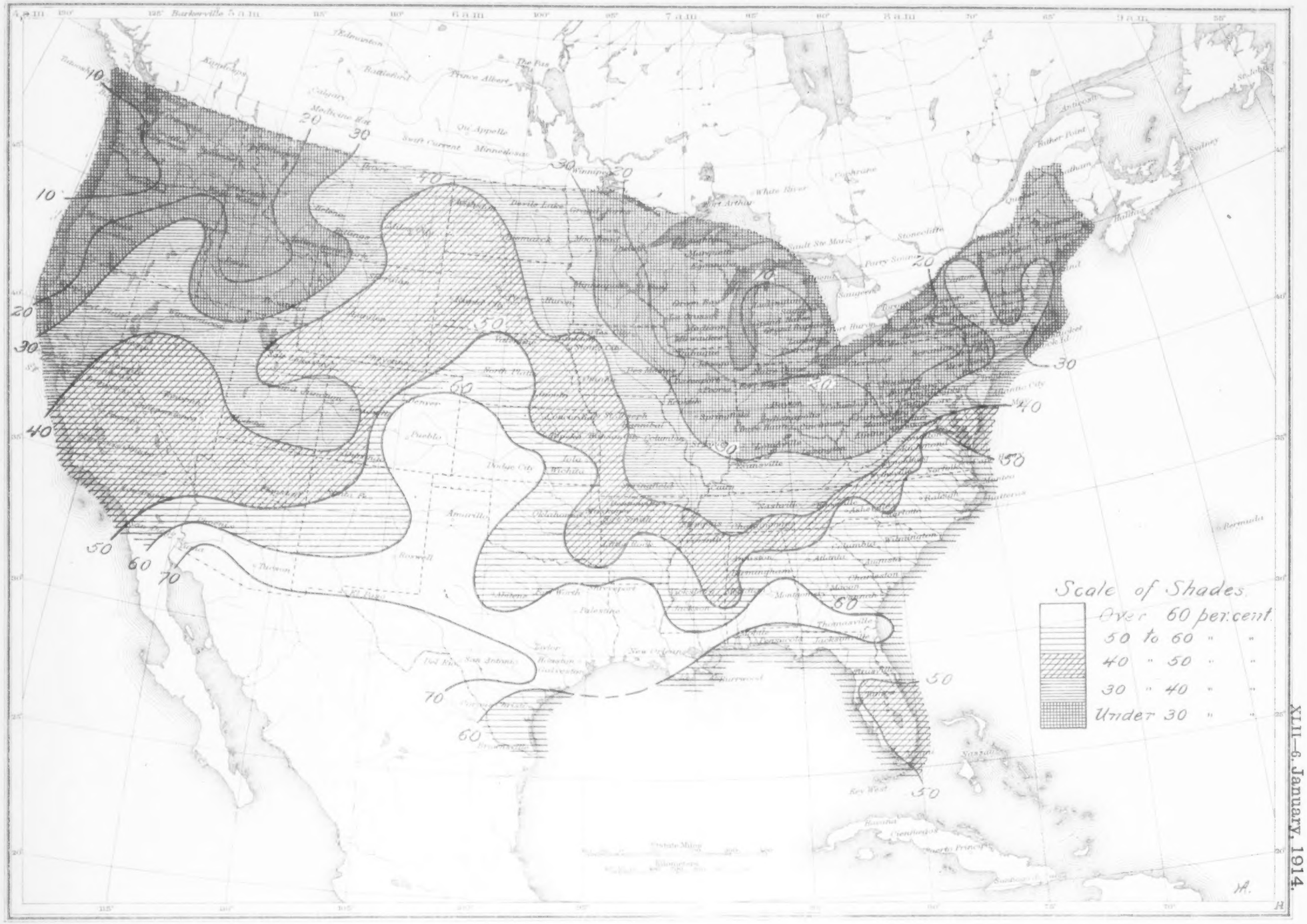
Chart IV. Departure of the Mean Temperature from the Normal, January, 1914.



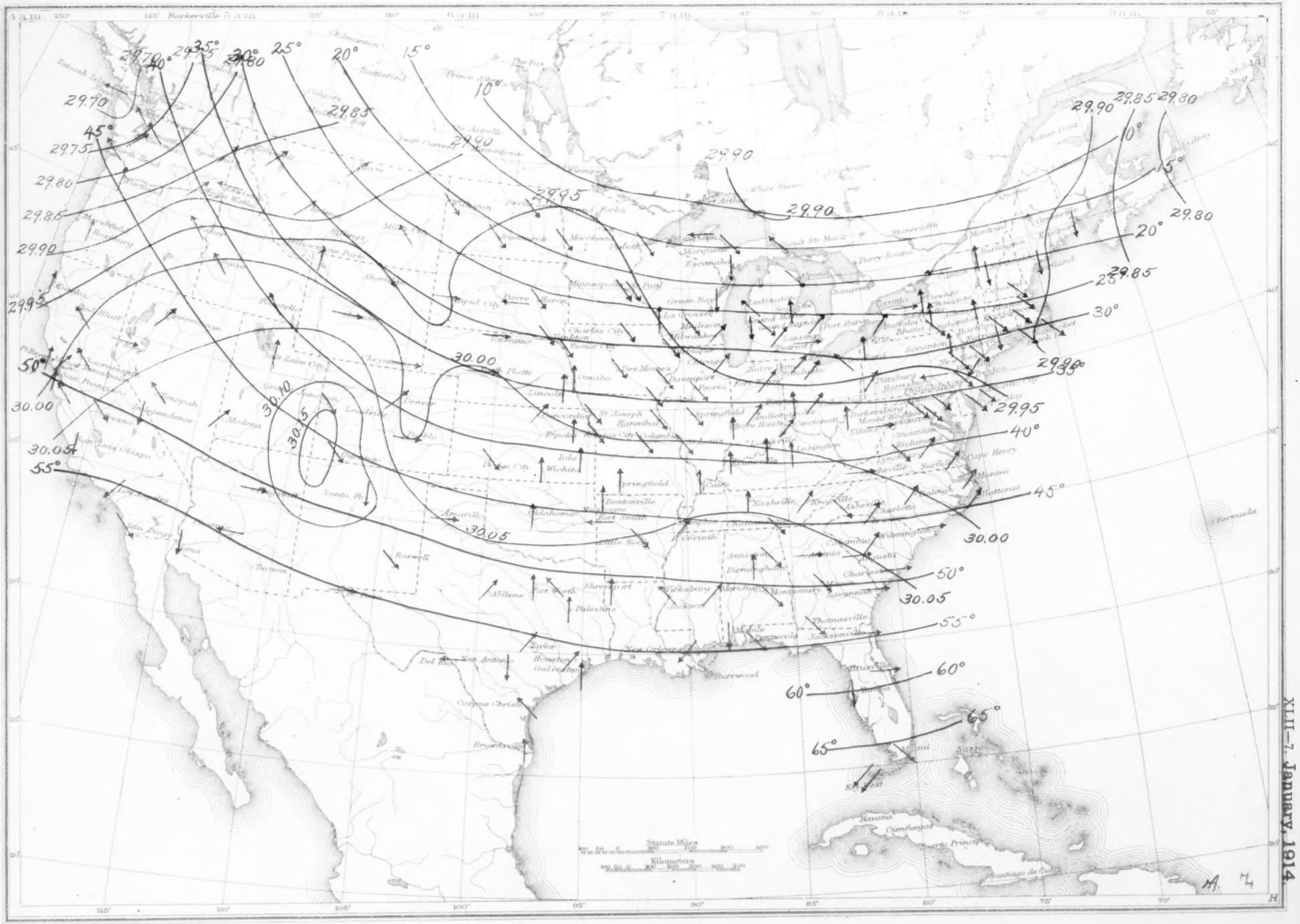
# Chart V. Total Precipitation, January, 1914.



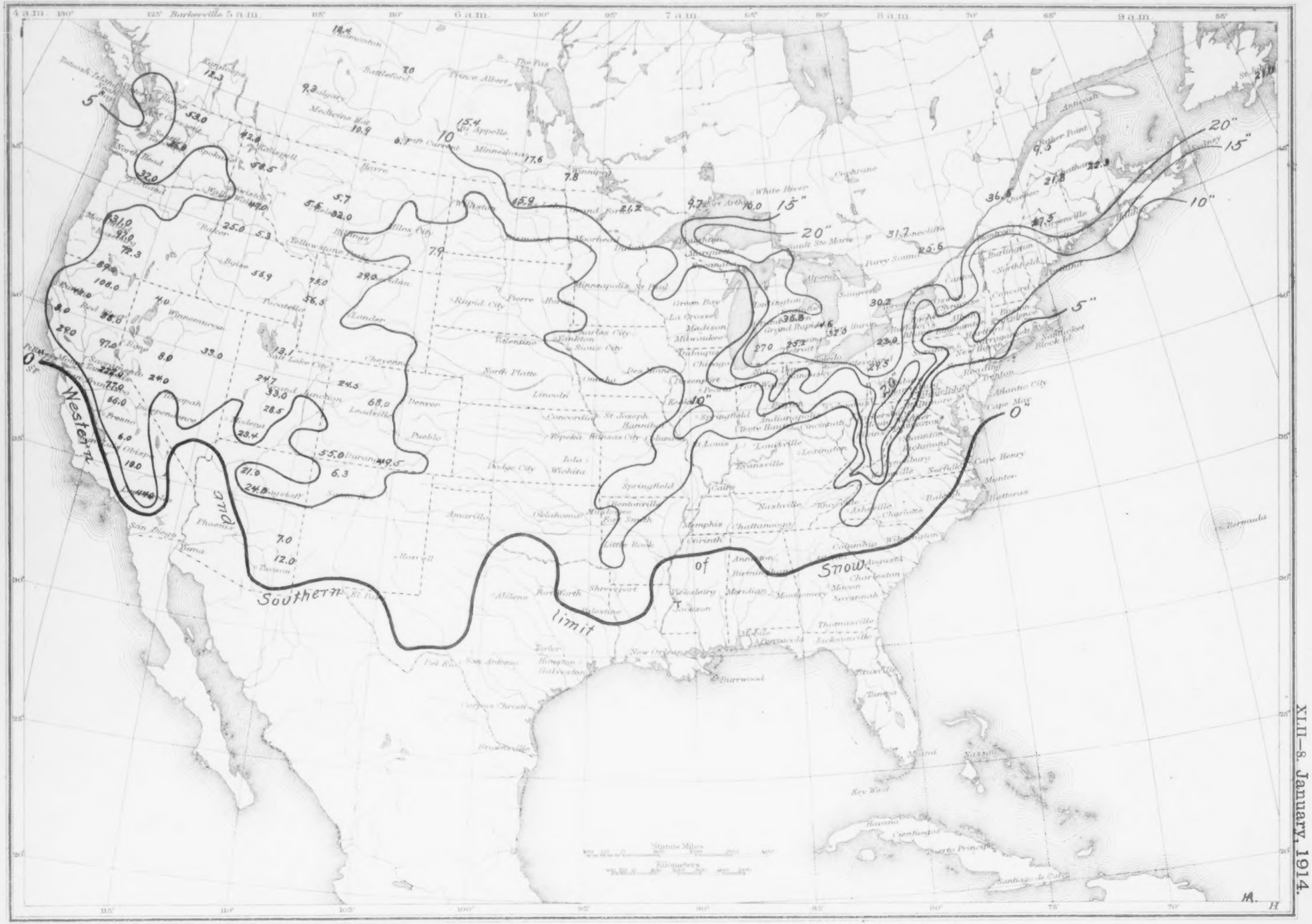
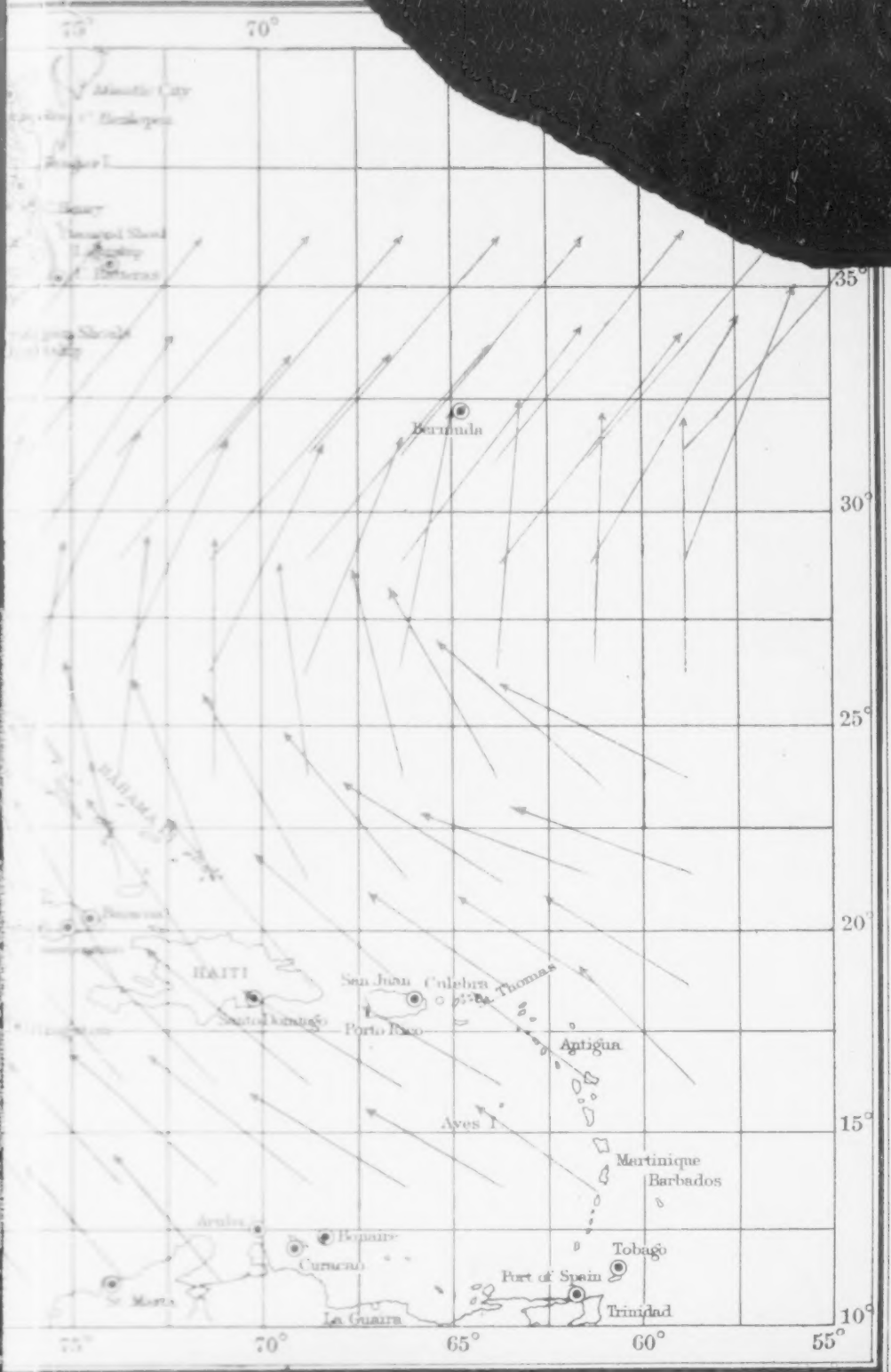
## Chart VI. Percentage of Clear Sky between Sunrise and Sunset, January, 1914.



# Chart VII. Isobars and Isotherms at Sea Level; Prevailing Winds, January, 1914.



# Chart VIII. Total Snowfall for January, 1914.



storms, by 2½°-squares.